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# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

DESIGN AND ANALYSIS OF A GENERALIZED  
CLASS OF FIN-LINE FILTERS

by  
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and  
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September 1983

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Design and Analysis of a Generalized Class of Fin-Line Filters

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## ABSTRACT

This study investigates fin-line filter structures, a type of E-plane waveguide device. Expressions germane to the analysis of fin-line structures are developed. A computer aided design and analysis program based upon a mode-matching technique is described. Filters designed by this program are fabricated and tested in X-band. Good agreement with predicted response is obtained. Filters fabricated and tested in Ku and Ka bands by other researchers are analyzed by the new program. Good agreement between predicted response and published performance is noted.





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## I. INTRODUCTION

Integrated circuits for use below about 3 GHz demonstrate clear advantages in terms of size, weight, cost and electrical performance, over alternative techniques. These advantages often accrue as a result of component miniaturization. However, as the frequency is increased to the centimeter and millimeter regimes, the resultant excessive miniaturization creates problems associated with critical mechanical tolerances, and questionable production uniformity. Moreover, concomitant undesirable electrical performance involving radiation loss, spurious coupling, dispersion and higher order mode propagation becomes unacceptable [Ref. 1]. Over the last decade, integrated fin-line structures have received increased attention as attractive media for low-insertion loss design applications which avoid excessive miniaturization, yet offer the potential for low-cost batch-processed production techniques.

The fin-line filter structure consists simply of conductive strips, or fins, which bridge the broad walls of a rectangular waveguide. That is, for waveguide operated in a  $TE_{m0}$  mode, the conducting fins are suspended in the E-plane. Metal sheet structures suspended in the center of the waveguide (herein referred to as "Class I" structures) offer the simplest possible structure for analysis and



design. These unilateral center-line fins present fabrication and suspension difficulties. Bilateral fin-line filters may be constructed as printed circuits on low-loss dielectric substrates and inserted in the center of the guide. These ("Class II") filters offer the advantage of construction by well developed printed circuit techniques, and relatively straight forward analysis [Refs. 2, 3], but still present the problem of mechanically fixing the fin-line structure in the center of the guide. Clearly, fin-line structures printed on dielectric substrate and affixed to the waveguide side-walls ("Class III" structures) offer mechanical advantages over the other two class types. The authors know of no previous investigations concerning Class III structures.

The purpose of this thesis study was to develop and validate a computer aided design (CAD) program for the design and analysis of all three class types of E-plane fin-line filters. To this end, the appropriate mathematical expressions were derived for a generalized fin-line structure.

The generalized structure has two different dielectric materials in the guide. The Class II filter described above corresponds to the case where the higher dielectric constant material is in the center of the guide. The Class III filter has the higher permittivity material along the waveguide walls. The generalized Class I filter has the same permittivity throughout the fin-line structure.





The derived transcendental equations relating the mode wave number values in different zones of the waveguide apply to all class types. However, when the difference in dielectric constants is large the trigonometric functions in the transcendental relationship may become hyperbolic. Moreover, Class II and Class III structures require different but equivalent expressions in the numerical analysis to avoid singularity occurrences.

The analysis method employed is a mode-matching technique uniquely applied to include the effects due to an arbitrary number of higher order modes. A convergence dependence analysis assures the most efficient regional distribution of the limited number of higher order modes retained for the numerical analysis.

Validation of the complete computer program for Class I and II filters was initially conducted by analyzing  $k_u$  and  $k_a$  band fin-line filters designed and constructed by Shih [Ref. 2], and Arndt, et al [Ref. 3]. Finally, several Class I and Class III filters were designed, constructed and tested locally. These test filters were resonant in X-band (8-12 GHz) to match available test hardware.



## II. THEORY

For the types of fin-line structures in waveguides considered here, each geometrical discontinuity may be considered in two distinct coordinate frames. It is useful, therefore, to expand the unknown fields in both regions in terms of their associated normal modes. Field continuity requirements are then imposed on the modes at the interface of the regions. Finally, the orthogonality property of the normal modes is used to derive an infinite set of linear simultaneous equations for the unknown modal coefficients. This is the essence of the mode-matching technique for the solution of boundary value problems [Ref. 4]. Moreover, this procedure leads directly to the scattering matrix for the discontinuity. Since the fin-line is a series of such discontinuities separated by transmission line sections, a cascading technique may be employed to develop an equivalent scattering matrix for the entire structure.

In principle, the effects of all the possible modes upon each of the others is inherently included, and the analysis is exact. In practice, the number of modes considered must be limited to a reasonably finite set. Accurate and efficient convergence of the subsequent numerical calculations is achieved by following the guidelines suggested by the studies of Shih and Gray [Ref. 5].



The derivation of the equivalent scattering matrix for the generalized fin-line structure follows. Detailed intermediate steps of the development are contained in the appropriate appendices. The basic geometry of the E-plane fin-line is shown in Fig. II-1. It is important to note that the assumed "magnetic wall" ( $x=0$ ), along which the parallel magnetic field is zero, implies  $TE_{m0}$  type ( $m$  odd) incident waveforms. The computer simulation is based upon a  $TE_{10}$  incident wave.

#### A. EXPRESSIONS FOR NORMAL MODES AND EIGENVALUES

By assuming incident modal electric (E) fields of the  $TE_{m0}$  type, field symmetries allow the simplified waveguide geometry shown in Fig. II-2. The conducting fin is assumed to be infinitely thin. The dielectric materials in the guide are assumed to be lossless, homogeneous, and isotropic. Also, the fin-line structures and substrates must be constructed to maintain symmetry about the  $x = 0$  plane. For simplicity of discussion, the guide is considered to be comprised of two regions, and two zones. The regions are  $Z$  dependent. Region I refers to the guide before the metal fin boundary, and Region II refers to the guide after (plus  $Z$  direction) the fin boundary. The zones are  $X$  dependent. Zone 1, sometimes called the lower zone, refers to the condition:

$$0 \leq x \leq d$$



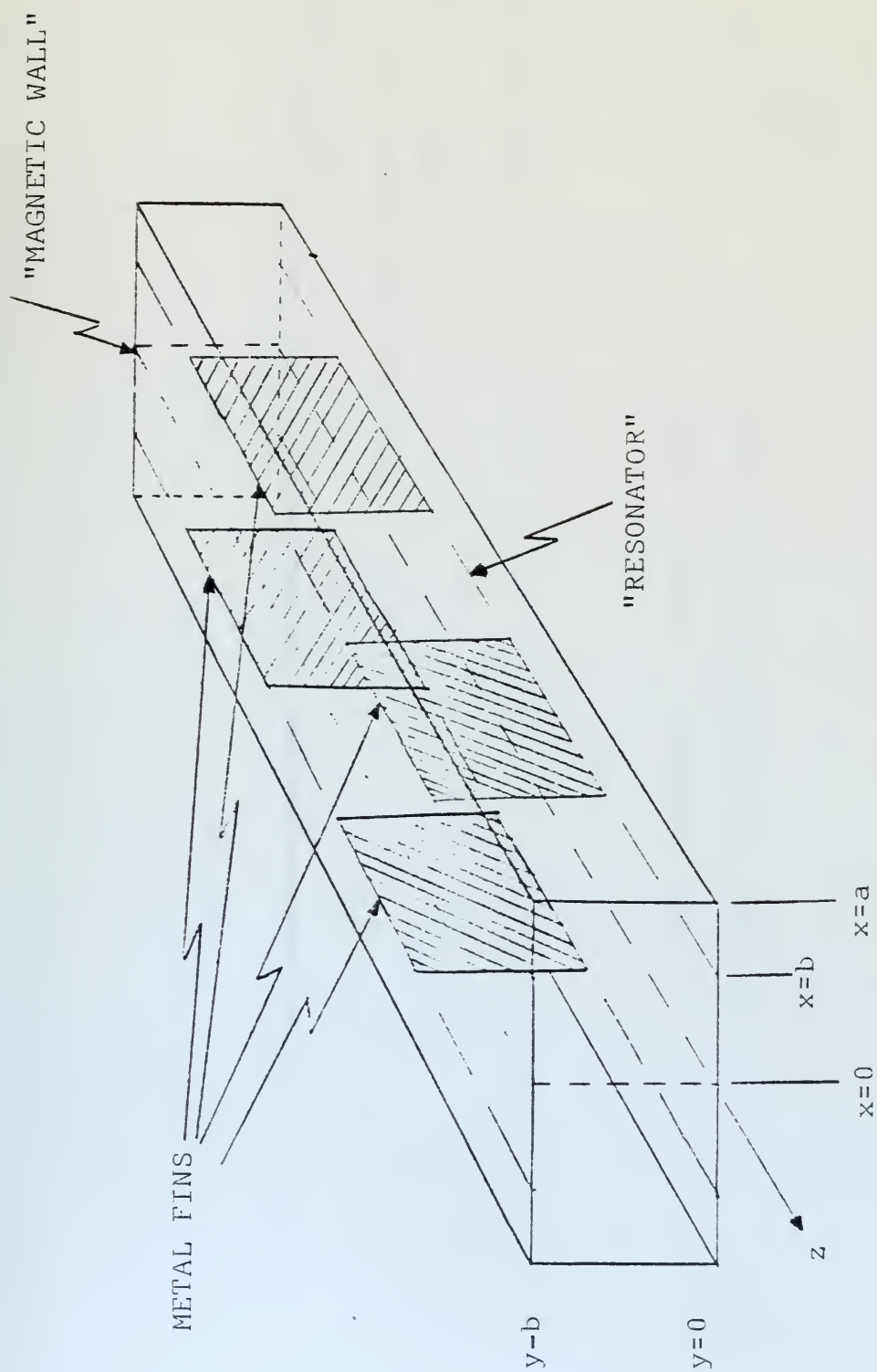
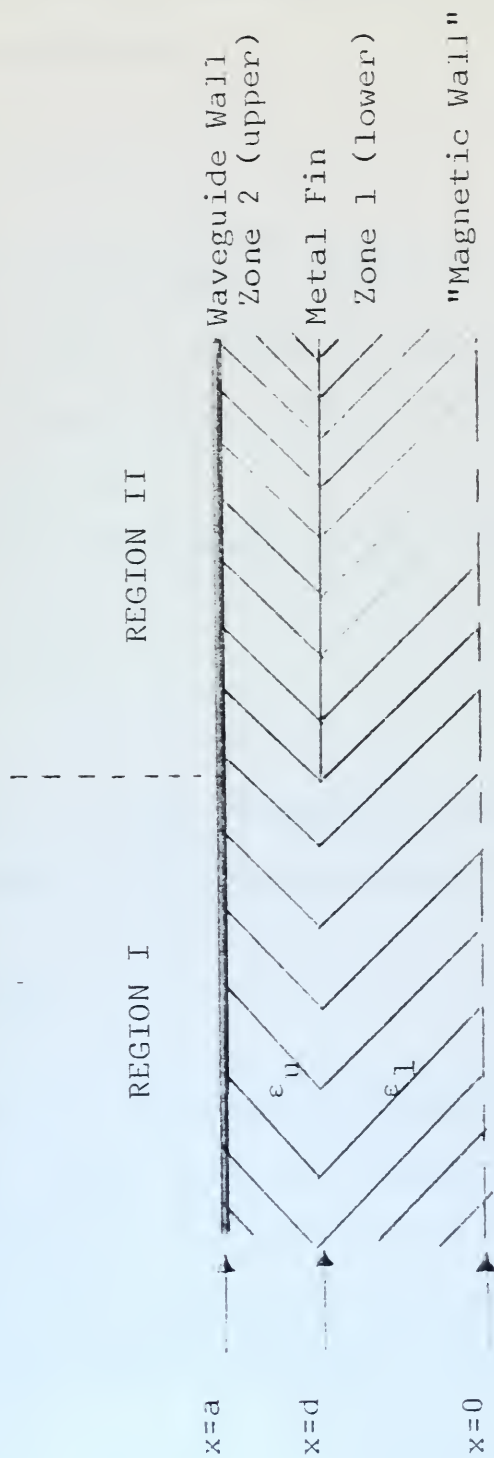


Fig. II-1. E-Plane Bilateral Fin-line Geometry









$\epsilon_u$  = Relative Dielectric Constant, upper

$\epsilon_l$  = Relative Dielectric Constant, lower

Fig. II.2. Simplified Waveguide Geometry



while Zone 2, sometimes called the upper zone, refers to the condition:

$$d \leq x \leq a.$$

Modal eigenvalues in Region I use lower-case subscripts, while those of Region II use upper-case. Regional divisions are occasionally indicated explicitly by the superscripts. "I" and "II".

The Z dependence of all fields is of the form:

$$e^{-\gamma_m z}$$

where  $\gamma_m$  is the propagation constant of the  $m^{\text{th}}$  mode.

Likewise, the time dependence of all fields is of the form:

$$e^{i\omega t}$$

where  $\omega$  is the radian frequency of the electromagnetic (EM) wave. These terms are understood to multiply all field expressions, and will not be explicitly shown, except where it is more convenient, or constructive to do so.

The general solution to the wave equation has the form:

$$[A_{jk} \cos k_j x_k + B_{jk} \sin k_j x_k] e^{i\omega t - \gamma_j z}$$



where the  $k_j$  are the associated wave numbers and the  $x_k$  are the appropriate directional variables,  $x$  or  $y$ .

For our purposes, the electric field in the  $Y$  direction,  $E_y$ , is of greatest interest. In Region I, the appropriate expressions for the normal modes of the  $E_y$  field are found to be (Appendix A):

$$\phi_n = \begin{cases} \Lambda_n \cos k_{1n} x & 0 \leq x \leq d \\ \Omega_n \sin k_{un}(a-x) & d \leq x \leq a \end{cases} \quad (\text{II.A.1})$$

with

$$\Omega_n = \left[ \left( \frac{\sin^2 k_{nn}(a-d)}{\cos^2 k_{1n}d} \right) \left( \frac{d}{2} + \frac{\sin 2k_{1n}d}{4k_{1n}} \right) + \left( \frac{a-d}{2} - \frac{\sin 2k_{un}(a-d)}{4k_{un}} \right) \right]^{-1/2}$$

$$\Lambda_n = \Omega_n \frac{\sin k_{un}(a-d)}{\cos k_{1n}d}.$$



The wave numbers for the  $n^{\text{th}}$  mode are related by the transcendental equations:

$$k_{1n}^2 = k_{un}^2 - k_o^2(\epsilon_u - \epsilon_l) \quad (\text{II.A.2})$$

$$\{ \begin{aligned} k_{1n} \tan k_{1n}d &= k_{un} \cot k_{un}(a-d) \end{aligned} \quad (\text{II.A.3})$$

where

$$k_o = \frac{2\pi}{\lambda_o} = \frac{2\pi f}{c} .$$

Equation II.A.2 is the usual dispersion relation, where  $\epsilon_l$  and  $\epsilon_u$  are the relative dielectric constants of the two zones. The transcendental equations (II.A.2) and (II.A.3) are solved simultaneously to determine the value of the wave number for each mode in both zones.

The corresponding expressions for Region II are similarly found to be:

$$\psi_p = \{ \begin{aligned} & \left(\frac{2}{d}\right)^{1/2} \cos k_{LP}x & : & 0 \leq x \leq d \\ & \left(\frac{2}{a-d}\right)^{1/2} \sin k_{UP}(z-x) & : & d \leq x \leq a . \end{aligned} \quad (\text{II.A.4})$$





The wave number for the  $p^{\text{th}}$  mode is:

$$k_{LP} = \frac{(2P-1)\pi}{2d} \quad ; \quad 0 \leq x \leq d$$

$$k_{UP} = \frac{P\pi}{(a-d)} \quad ; \quad d \leq x \leq a .$$

It should be noted that in Region II, the eigenvalues for  $k_{LP}$  are uncoupled from the eigenvalues for  $k_{UP}$  so that the mode number,  $p$ , runs from 1 to  $\infty$  individually in each zone. The propagation number for the  $m^{\text{th}}$  mode in Region I is given by:

$$\gamma_m^I = (K_{1m}^2 - \epsilon_1 k_o^2)^{1/2} \quad 0 \leq x \leq a .$$

The Region II propagation numbers are given by:

$$\gamma_p^{II} = \begin{cases} (k_{LP}^2 - \epsilon_L k_o^2)^{1/2} & 0 \leq x \leq d \\ (k_{UP}^2 - \epsilon_U k_o^2)^{1/2} & d \leq x \leq a . \end{cases}$$

Positive real values for the propagation number corresponds to evanescent waves. Propagating wave modes occur when the propagation number is imaginary.



## B. MODAL ANALYSIS

Any physically realizable electric field may be written as some linear combination of the normal modes. That is:

$$E_y^I = \sum_{n=1}^{\infty} A_n \phi_n$$

and

$$E_y^{II} = \sum_{p=1}^{\infty} D_p \psi_p$$

The  $\phi_n$  and  $\psi_p$  are the normal modes of the  $E_y$  field in Region I and Region II, respectively. The  $A_n$  and  $D_p$  are the associated amplitudes.

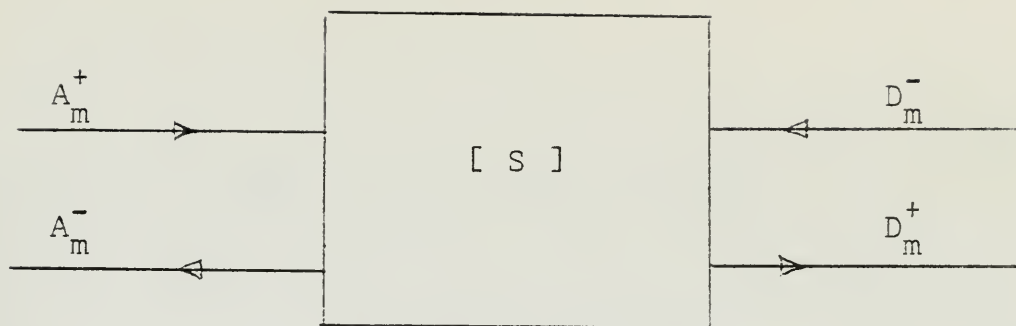
The interface discontinuity may be analyzed as a two port junction, with values as defined in Fig. II-3. The boundary conditions on the  $\phi_n$  and  $\psi_p$  [Ref. 4] require that:

$$\sum_{n=1}^{\infty} A_n^+ \phi_n + \sum_{n=1}^{\infty} A_n^- \phi_n = \sum_{p=1}^{\infty} D_p^+ \psi_p + \sum_{p=1}^{\infty} D_p^- \psi_p$$

and

$$\begin{aligned} \sum_{n=1}^{\infty} Y_n^I A_n^+ \phi_n - \sum_{n=1}^{\infty} Y_n^I A_n^- \phi_n &= \sum_{p=1}^{\infty} Y_p^{II} D_p^+ \psi_p \\ &- \sum_{p=1}^{\infty} Y_p^{II} D_p^- \psi_p \end{aligned}$$





$A_m^+$  = Coefficients of Modes Incident from the Left

$A_m^-$  = Coefficients of Modes leaving junction to the Left

$D_m^-$  = Coefficients of Modes Incident from the Right

$D_m^+$  = Coefficients of Modes leaving junction to the Right.

$[S]$  = Scattering Matrix

Fig. II-3. Two-port Junction Model of Discontinuity



The characteristic impedance of the  $n^{\text{th}}$  mode,  $Y_n$ , is defined by:

$$-j\omega u(H_z)_n = \frac{\partial \phi_n}{\partial z} = -\gamma_n \phi_n \rightarrow (H_z)_n = Y_n \phi_n .$$

Whence,

$$Y_n = \frac{\gamma_n}{j\omega u} . \quad (\text{II.B.1})$$

The orthogonality of the normal modes implies that:

$$\sum_{n=1}^{\infty} (A_n^+ + A_n^-) \int_0^a \phi_n \psi_m dx = \sum_{p=1}^{\infty} (D_p^+ + D_p^-) \int_0^a \psi_p \psi_m dx$$

$$= \sum_{p=1}^{\infty} (D_p^+ + D_p^-) \delta_{pm}$$

where  $\delta_{pm}$  is the kronecker delta.

We define the coupling coefficients,  $H_{mn}$ , by:

$$H_{mn} \equiv \int_0^a \phi_n \psi_m dx .$$





Whence,

$$\sum_{n=1}^{\infty} (A_n^+ + A_n^-) H_{mn} = D_m^+ + D_m^- .$$

Similarly, we can write:

$$\begin{aligned} \sum_{n=1}^{\infty} Y_n^I (A_n^+ - A_n^-) \int_0^a \phi_n \phi_m dx &= Y_m^I (A_m^+ - A_m^-) \\ &= \sum_{p=1}^{\infty} Y_p^{II} (D_p^+ - D_p^-) \int_0^a \psi_p \phi_m dx \end{aligned}$$

or, since the p is a dummy summation index,

$$Y_m^I (A_m^+ - A_m^-) = \sum_{n=1}^{\infty} Y_n^{II} (D_n^+ - D_n^-) H_{nm} .$$

By representing the A and D amplitudes as vectors, and the H coupling coefficients and Y impedance terms as matrices, these relationships may be expressed more succinctly as:

$$[H_{mn}] [A_n^+ + A_n^-] = [D_m^+ + D_m^-]$$

$$[Y_m^I] [A_m^+ - A_m^-] = [Y_n^{II}] [H_{mn}]^T [D_m^+ - D_m^-] .$$



The  $[H_{mn}]^T$  represents the transpose of the matrix  $[H_{mn}]$ . The elements of  $[H_{mn}]$  may be evaluated by direct substitution of the expressions for the normal modes (Eqs. II.A.1 and II.A.4) into the definition (II.B.2). From Appendix B we write:

$$H_{mn} = \Lambda_n \left(\frac{2}{d}\right)^{1/2} ((-1)^m \cos k_{1n} d) \left(\frac{k_{Lm}}{k_{1n}^2 - k_{Lm}^2}\right) \\ + \Omega_n \left(\frac{2}{a-d}\right)^{1/2} ((-1)^m \sin k_{un} (a-d)) \left(\frac{k_{Um}}{k_{un}^2 - k_{Um}^2}\right) .$$

The scattering matrix for a single junction is defined in Appendix C to have matrix elements (which are themselves matrices) as follows:

$$[S_A] = \begin{bmatrix} S_{A11} & S_{A12} \\ S_{A21} & S_{A22} \end{bmatrix}$$

$$S_{A11} = [Y^I + H^T Y^{II} H]^{-1} [Y^I - H^T Y^{II} H] \quad (II.B.3)$$

$$S_{A12} = 2[Y^I + H^T Y^{II} H]^{-1} [H^T Y^{II}] = [I - S_{A11}] H^T$$

$$S_{A21} = 2[I + H(Y^I)^{-1} H^T Y^{II}]^{-1} H = H[I + S_{A11}]$$

$$S_{A22} = [I + H(Y^I)^{-1} H^T Y^{II}]^{-1} [H(Y^I)^{-1} H^T Y^{II} - I] = -H[S_{A11}] H^T .$$



Note that each of the individual elements, H, Y, T, and I are themselves matrices. For a single fin-line strip there is a scattering matrix associated with the left boundary (minimum Z),  $[S_A]$ , described above, a transmission matrix associated with the width of the strip,  $[T_D]$ , and a scattering matrix associated with the right boundard,  $[S_B]$ . The expression for an equivalent scattering matrix for the net effect of  $[S_A]$ ,  $[T_D]$ , and  $[S_B]$ , is developed in detail in Appendix D. The result is:

$$[S_E] = \begin{bmatrix} S_{E11} & S_{E12} \\ S_{E21} & S_{E22} \end{bmatrix}$$

where:

$$S_{E11} = [S'_{A11}] + [S'_{A12}][I - S_{B11} S'_{A22}]^{-1} [S_{B11} S'_{A21}]$$

$$S_{E12} = [S'_{A12}][I - S_{B11} S'_{A22}]^{-1} [S_{B12}]$$

(II.B.4)

$$S_{E21} = [S'_{A21}][I - S_{B22} S'_{A11}]^{-1} [S_{B21}]$$

$$S_{E22} = [S'_{A21}][I - S_{B22} S'_{A11}]^{-1} [S_{B22} S'_{A12}] + [S'_{A22}]$$

and

$$S'_A = [T_D][S_A][T_D] \quad .$$



The equivalent scattering matrix for a fin-line with an arbitrary number of fins may be determined by repeated application of equations (II.B.4), with the appropriate transmission matrices used in the cascade.





### III. COMPUTER AIDED DESIGN PROGRAM

The CAD (computer aided design) program has two functions: 1) design of a filter (description of physical dimensions) based upon user specified characteristics; and 2) analysis of a physically described fin-line filter. The user has the option of directly entering the analysis portion of the CAD if filter dimensions have been determined by some other means. In most cases, however, the user will specify the desired response of the fin-line filter (bandedge frequencies, passband ripple and upper skirt rejection) and the CAD will determine the filter dimensions. These dimensions are then automatically passed to the analysis portion of the CAD.

The design portion of the CAD is built upon the theoretical work of Levy [Refs. 6, 7] and contains a modified form of a subroutine developed by Shih in [Ref. 2]. The design technique is fundamentally a conventional network synthesis. The insertion-loss characteristic of the distributed filter is approximated by the equation:

$$L = 1 + h^2 T_n^2 \left[ \frac{\lambda_g}{\lambda_{go}} \frac{\sin(\lambda_g / \lambda_{go})}{\sin \theta'_0} \right] .$$

where:

$h$  is the passband ripple

$\lambda_g$  is the guide wavelength



$\lambda_{g0}$  is the guide wavelength at the filter center frequency

$$\sin \theta'_0 = \frac{\lambda_{g1}}{\lambda_{g0}} \sin \frac{\lambda_{g0}}{\lambda_{g1}} = \frac{\lambda_{g2}}{\lambda_{g0}} \sin \frac{\lambda_{g0}}{\lambda_{g2}}$$

$\lambda_{g1}(\lambda_{g2})$  is the guide wavelength at filter bandedge,  $f_1(f_2)$

$T_n$  is the first-kind Chebyshev polynomial of degree  $n$

$n$  is the number of filter resonators.

The insertion loss equation is evaluated for the input specifications to determine the number of resonators required. To properly determine the number of resonators for the general case, it was necessary to develop subroutines to solve simultaneously the transcendental equations for the wave numbers of the eigenmodes. The functional dependency of the insertion loss equation, above, on guide wavelength is ambiguous for the Class II and Class III filter. Thus, it was also necessary to determine an "effective" guide wavelength which accounts for the fact that the wavelength changes as the wave propagates from one dielectric region into another. It is this effective guide wavelength which is used in Levy's formula. The required reflection coefficients of the  $n+1$  fins are then derived from the Chebyshev polynomial. Next, the scattering matrix for a finite septum (Eqs. II.B.3) is evaluated by a bisection technique to determine the  $n+1$  fin dimensions which satisfy



these reflection coefficient requirements. Finally, the resonator dimensions are determined so that the electrical length of each resonator is  $(1/2) \lambda_{go}$ .

With the dimensions of the filter thus determined, the CAD then performs a complete frequency response analysis based upon the mode-matching technique described in Sections II.A and II.B. It should be noted that the equal-ripple Chebyshev polynomial expression very accurately matches the computed response when the filter is narrow band (less than 4% bandwidth). The agreement between the Chebyshev filter approximation and the mode-matching scattering analysis deteriorates as the filter bandwidth increases. A thorough discussion of this phenomenon is given by Shih in [Ref. 8] along with new formulae which account for the frequency dependencies of the step-impedances. However, excellent agreement between design criteria and predicted response has been obtained by employing an empirically derived offset to the lower bandedge frequency. That is, if the user specifies the filter bandedges to be  $F1$  and  $F2$ , the design portion is actually computed for bandedge frequencies:

$$F1' = F1 \left( 1 - \left( \frac{2(F2-F1)}{F2+F1} \right)^2 \right), \text{ and } F2.$$



The program listing given in Appendix F includes those subroutines which were developed as a consequence of the previously discussed theory. Subroutine TREQ develops eigenmode wave numbers for all three filter classes. Subroutine PROPAG determines the corresponding propagation numbers. Subroutine SMATRI determines the values of the H matrix coupling coefficients, and the elements of the scattering matrix. Subroutines CASCAD, DSUM, and TRANSM are used to determine the net effect of several cascaded fins and resonators, as discussed in Appendix E.

Certain subroutines used in the design portion of the program are substantially the work of Shih [Ref. 2], and are not included in the program listing. Also omitted are certain mathematical and algebraic routines required for the matrix manipulations.







#### IV. PROGRAM VALIDATION

##### A. OVERVIEW

The first phase of program validation was conducted as critical subroutines became available. For example, the subroutine which determines wave mode numbers was tested for special circumstances for which the values could be verified by means of a hand calculator. A series of tests were then made to assure convergence to this limiting case. Professor Y. C. Shih kindly modified subroutines extracted from his work [Ref. 2] to output values at intermediate stages of his analysis routine. These numerical values were of interest because they were determined from closed-form expressions for the reflection coefficients, and employed a residue calculus technique. Thus, the corresponding values determined by the new program were evaluated from a completely different set of expressions and based upon a fundamentally different approach to the problem. Correspondence between equivalent values was considered good to within the accuracy of the numerical process.

Predicted filter responses were compared to actual filter performance to validate further the computer aided design and analysis program. Dimensions for Class I and Class II filters described by Shih [Ref. 2] and Arndt, et al, [Ref. 3] were inserted into the analysis portion of



the CAD and filter performance was predicted over an appropriate frequency range. The agreement between predicted response and published filter performance was excellent. Lastly, final validation of the CAD was accomplished by means of locally designing, constructing and testing three Class I and two Class II fin-line filters.

## B. FILTER CONSTRUCTION AND TEST

The locally constructed test filters were designed to be resonant within the 8 to 12 GHz band. This frequency band choice was selected to simplify both filter construction and test.

The three Class I filters were manually cut with scissors and razor blades from a 2 mil(0.002 inch) copper foil. The narrow band Class III filter was made by manually cutting away the 2 mil copper layer from 1/8" copper clad substrate (Rexolite 1422). The substrate for the wideband Class III filter was a slab of styrofoam cut from a packing form. Conducting fins were cut from 2 mil copper tape and pressed onto the styrofoam slab to form the filter structure.

The test fixture used was a specially machined ten inch aluminum section of WR-90 compatible waveguide (0.9 by 0.4 inch, internal), modeled after a design by Knorr [Ref. 9]. This guide consisted to two longitudinal sections which were bolted together. The transverse dimension of the



Class I filter was made equal to the test fixture exterior dimension. It was a simple matter, therefore, to separate slightly the test guide halves, slip in the fin-line structure, and tighten the clamping bolts. While this introduced a 2 mil dimension distortion in the center area of the test fixture, no adverse effects were noted.

The fin-line structure of the Class III filter was pressed into the opened waveguide groove. A small spot of rubber cement served to hold the dielectric substrate against the guide wall.

Filter electrical performance was measured with the aid of an HP-8409 automated network analysis system.

## C. RESULTS

A plot of normalized throughput power versus frequency for seven filters is shown in Figures IV-1 through IV-7, for Filters #1 through #7, respectively. Filters #1 through #4 and #7 were fabricated by the authors. For these figures the continuous curve is a plot of the predicted filter response generated by the CAD. The circles contain measurement data points. Filters #5 and #6 are representative filters described by Arndt, et al [Ref. 3]. Again, the line is the CAD generated plot, but the data points on these curves were taken from figures contained in [Ref. 3]. Table IV-1 contains the physical descriptors of the filters.





Filters #1 and #2 are Class III type structures; filters #3, #4 and #7 are Class I; filters #5 and #6 are Class II. In general, the shape of the filter response corresponds well to the simulated filter. Actual filter passband ripple was more than predicted, and varied from a best case of 0.1 dB (#1) to a worst case of 3.0 dB (#2). Best case insertion loss (Filters #1 and #7) was about 0.3 dB. Modifications to existing filters and multiple construction attempts at the same design suggests that the majority of the discrepancy in predicted and actual response was due to error in the hand-out filter dimensions.

The good agreement between predicted and actual filter response is readily seen for filters #4, #6 and #7 (Figures IV-4, IV-6, IV-7). In other instances the agreement is less apparent because of the expanded scale of the plot. For example, the discrepancy between predicted and actual response of filter #1 may be almost entirely accounted for by a shift in center frequency of about 150 MHz. This 150 MHz shift represents about a 1.7% error in center frequency and could result from a construction error in resonator dimension of about 0.3 mm.

Filter #7 is particularly interesting because it demonstrates the utility of the program. This filter was designed to satisfy a requirement of a physics researcher. Total time logged on the computer was about 15 minutes.





A copy of the output to the CRT is given in Appendix G. The CAD determined filter dimensions were scribed onto a sheet of copper foil and the filter was cut out by hand. Total construction time was about one hour. Figure IV-8 is a copy of the test equipment output, with notations added. The minimum measured insertion loss was 0.28 dB at 8.604 GHz. Passband ripple was measured at 0.39 dB. The lower 3 dB point was measured at 8.360 GHz and the higher 3 dB point was measured at 8.823 GHz. Thus, the CAD analysis values for the 3 dB frequency cutoffs of about 8.37 GHz and 8.85 GHz compare to within 0.3% of the measured values. The researcher considered the more than 60 dB of out-of-band rejection provided by this filter to be quite adequate.

#### D. DISCUSSION

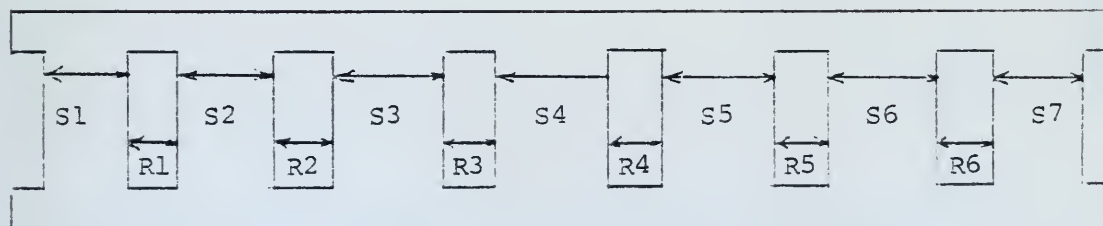
Experiences related to the design, fabrication and test of the fin-line filters motivates us to catalogue a number of observations which may be useful to others.

First, it should be stressed that the filters constructed were very crude by industry standards. Dimensional tolerances are estimated at  $\pm 0.4$  mm. Thus, the dimensional accuracy of the smallest fins is roughly bounded by  $\pm 40\%$ . The reasonably good electrical performance of these filters was, therefore, all the more striking. Also, it should be noted that the approximate 150 MHz shift in center frequency for filter #1 (narrow band Class III) can be the result of about a 0.3 mm error in the construction of the resonator dimension.

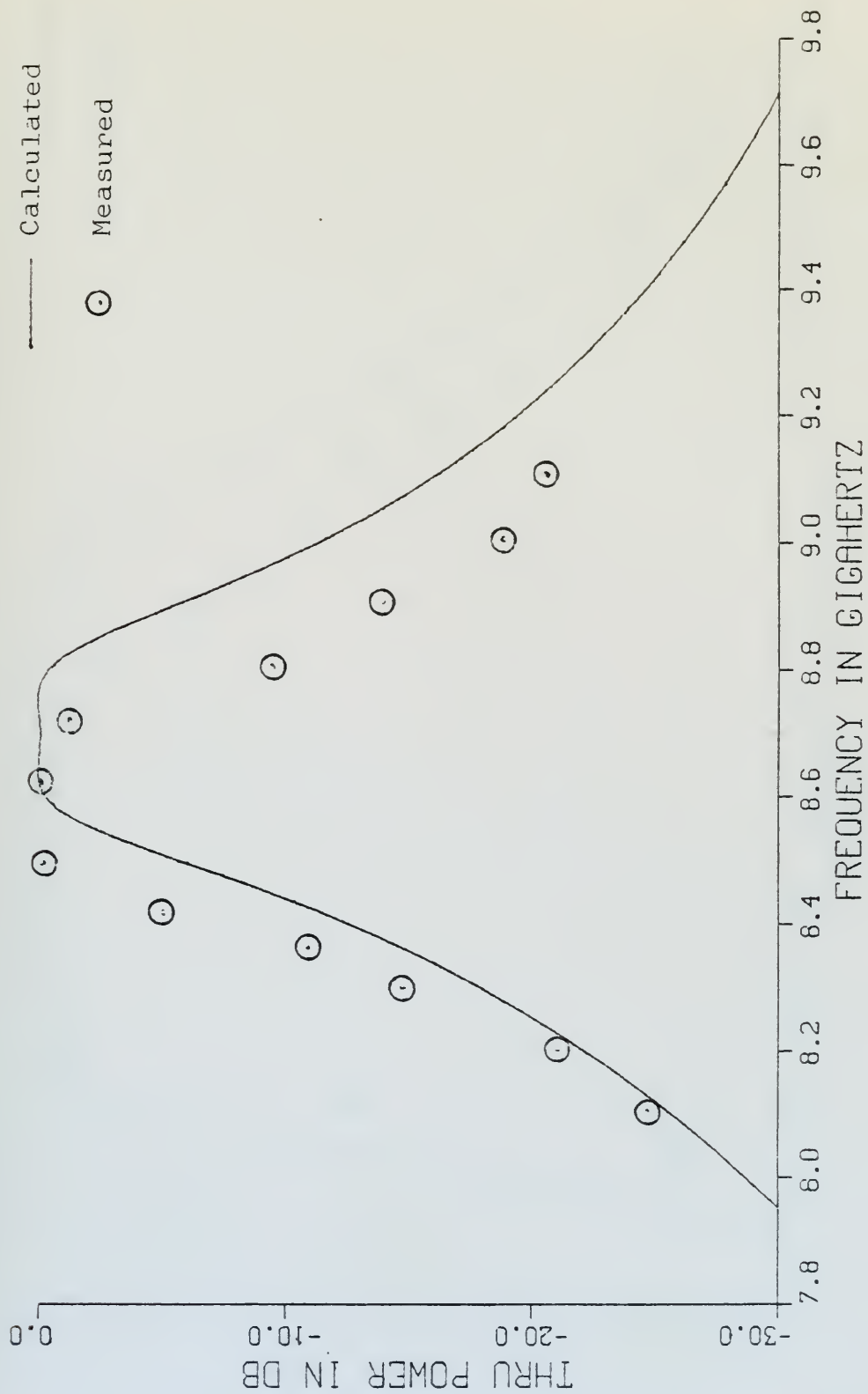


TABLE IV-1  
DESIGN DATA FOR CAD VALIDATION TEST FILTERS

Filter #	1	2	3	4	5	6	7
a(cm)	1.143	1.143	1.143	1.143	.7895	.188	1.143
d(cm)	0.508	0.508	0.508	0.508	.0127	.00635	0.508
$\epsilon_u$ (upper)	2.550	1.030	1.000	1.000	1.0	1.0	1.000
$\epsilon_l$ (lower)	1.000	1.000	1.000	1.000	2.22	2.22	1.000
F1(GHz)	8.625	9.950	8.450	11.30	15.00	66.0	8.400
F2(GHz)	8.775	10.95	8.850	11.75	15.60	67.0	8.800
# Strips	3	6	4	4	4	4	7
# Res	2	5	3	3	3	3	6
S1 (cm)	.0959	0.1485	.0732	.4995	.2075	.0347	.0906
S2 (cm)	.4928	0.7782	.4185	1.4252	.7760	.2038	.4794
S3 (cm)	.0959	1.0040	.4185	1.4252	.7760	.2038	.5961
S4 (cm)	---	1.0040	.0732	.4995	.2075	.0347	.6134
S5 (cm)	---	0.7782	---	---	---	---	.5961
S6 (cm)	---	0.1485	---	---	---	---	.4794
S7 (cm)	---	---	---	---	---	---	.0906
R1 (cm)	1.5044	1.1435	1.9991	.9398	.8400	.1895	2.0480
R2 (cm)	1.5044	1.1142	2.0728	.9265	.8400	.1900	2.1227
R3 (cm)	---	1.1104	1.9991	.9398	.8400	.1895	2.1280
R4 (cm)	---	1.1142	---	---	---	---	2.1280
R5 (cm)	---	1.1435	---	---	---	---	2.1227
R6 (cm)	---	---	---	---	---	---	2.0480



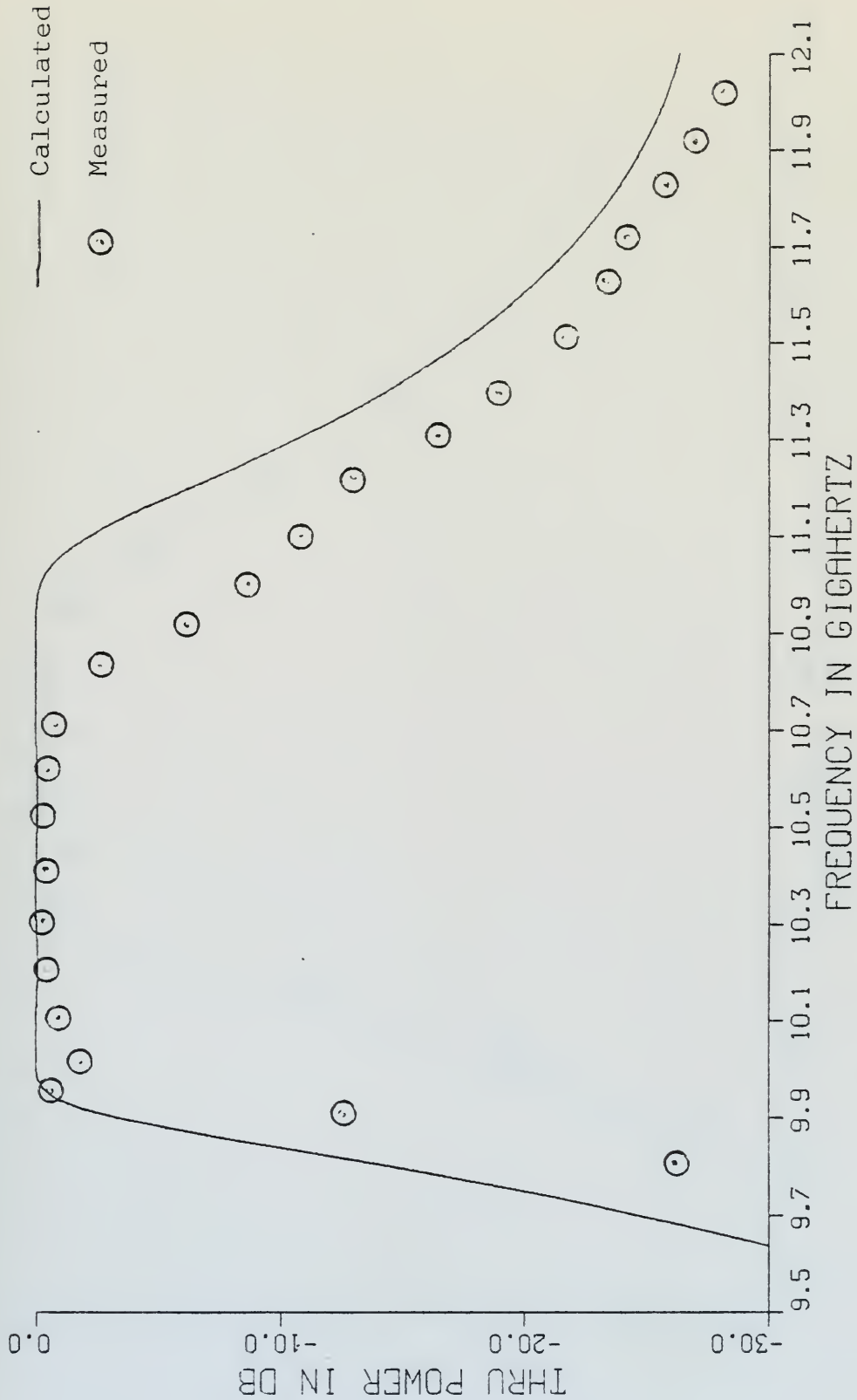




### FILTER 1.

Fig. IV-1. Calculated and Measured Insertion Loss of Fin-line #1



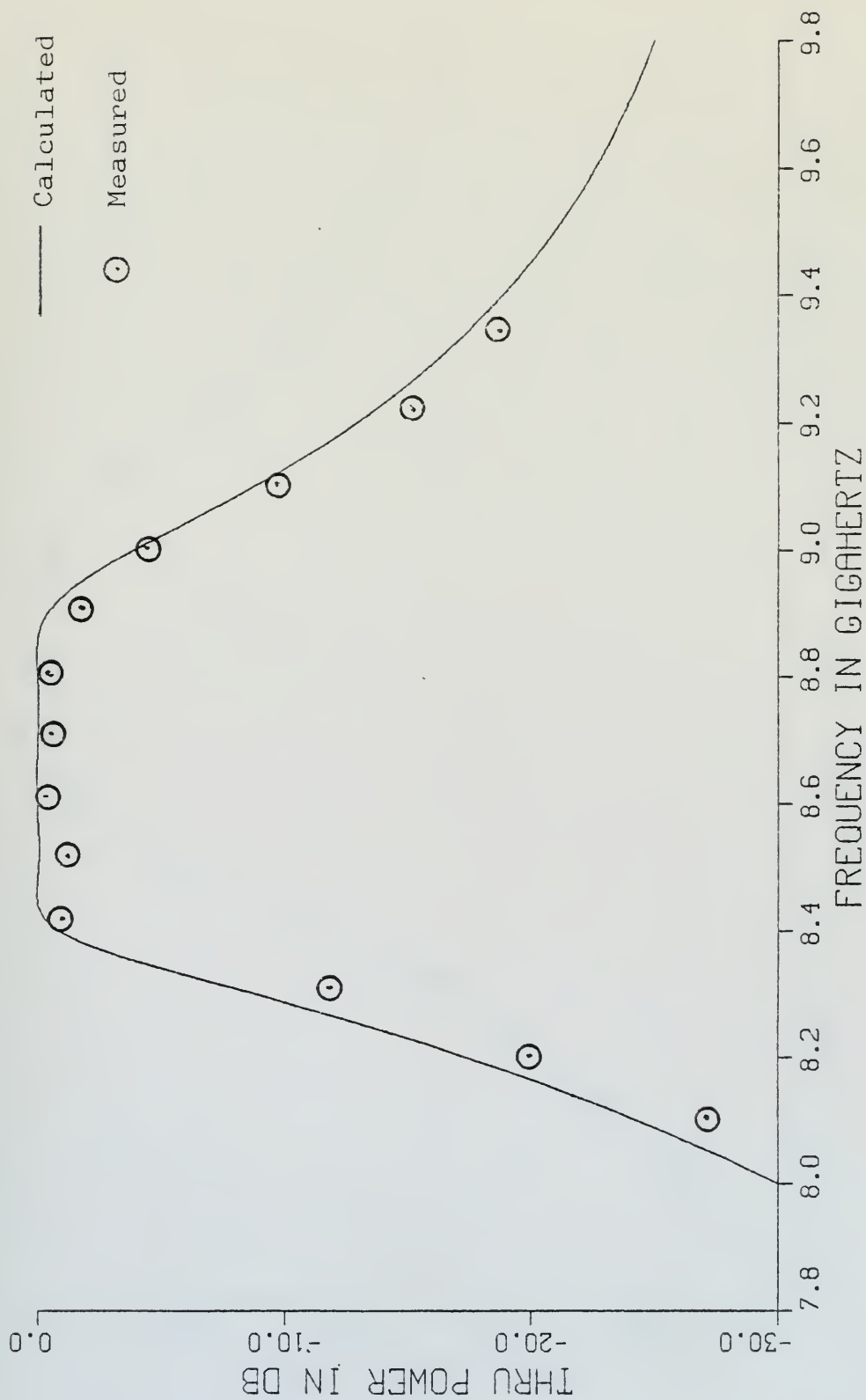


## FILTER 2.

Fig. IV-2. Calculated and Measured Insertion Loss of Fin-line #2



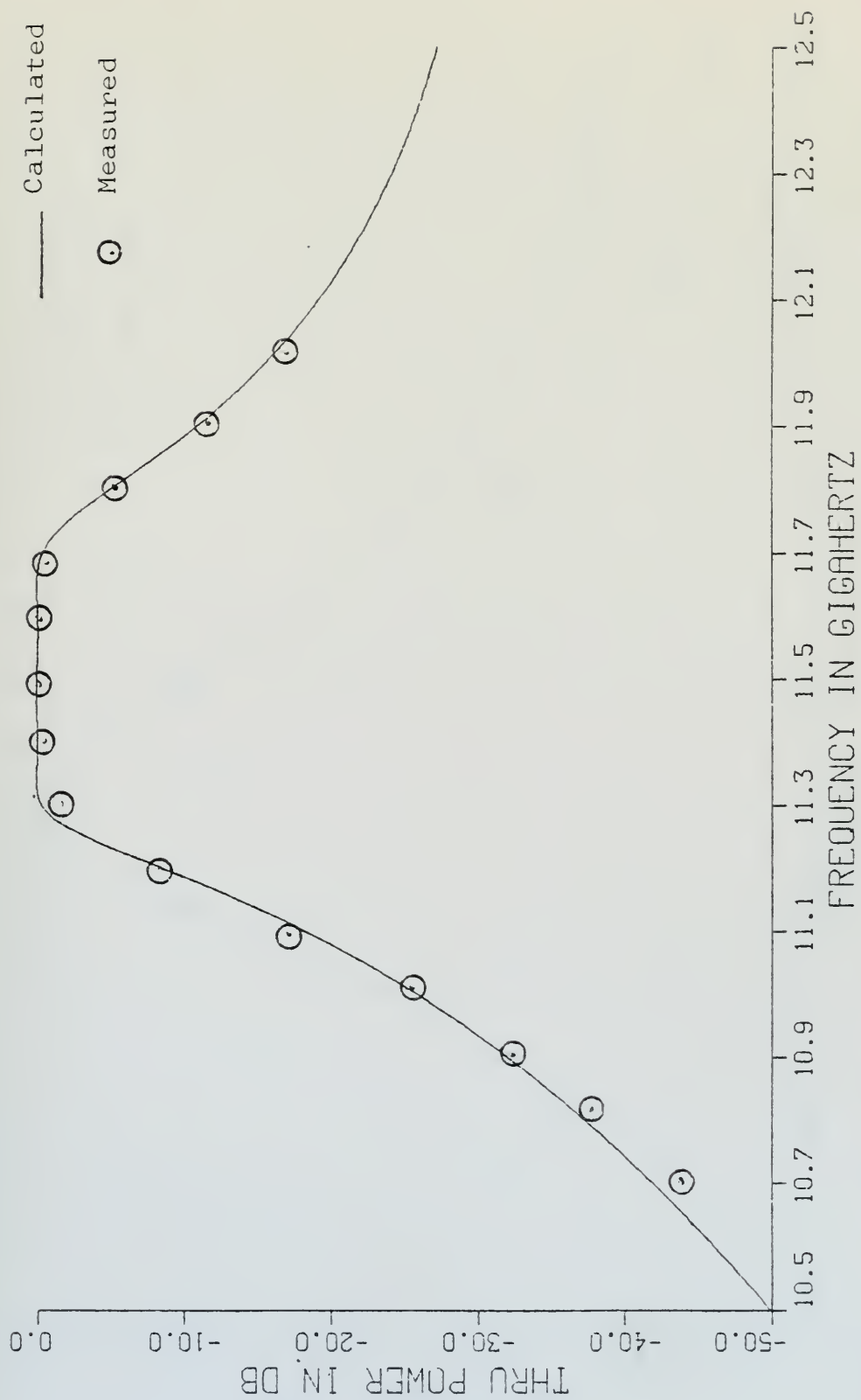




### FILTER 3.

Fig. IV-3. Calculated and Measured Insertion Loss of Fin-line #3

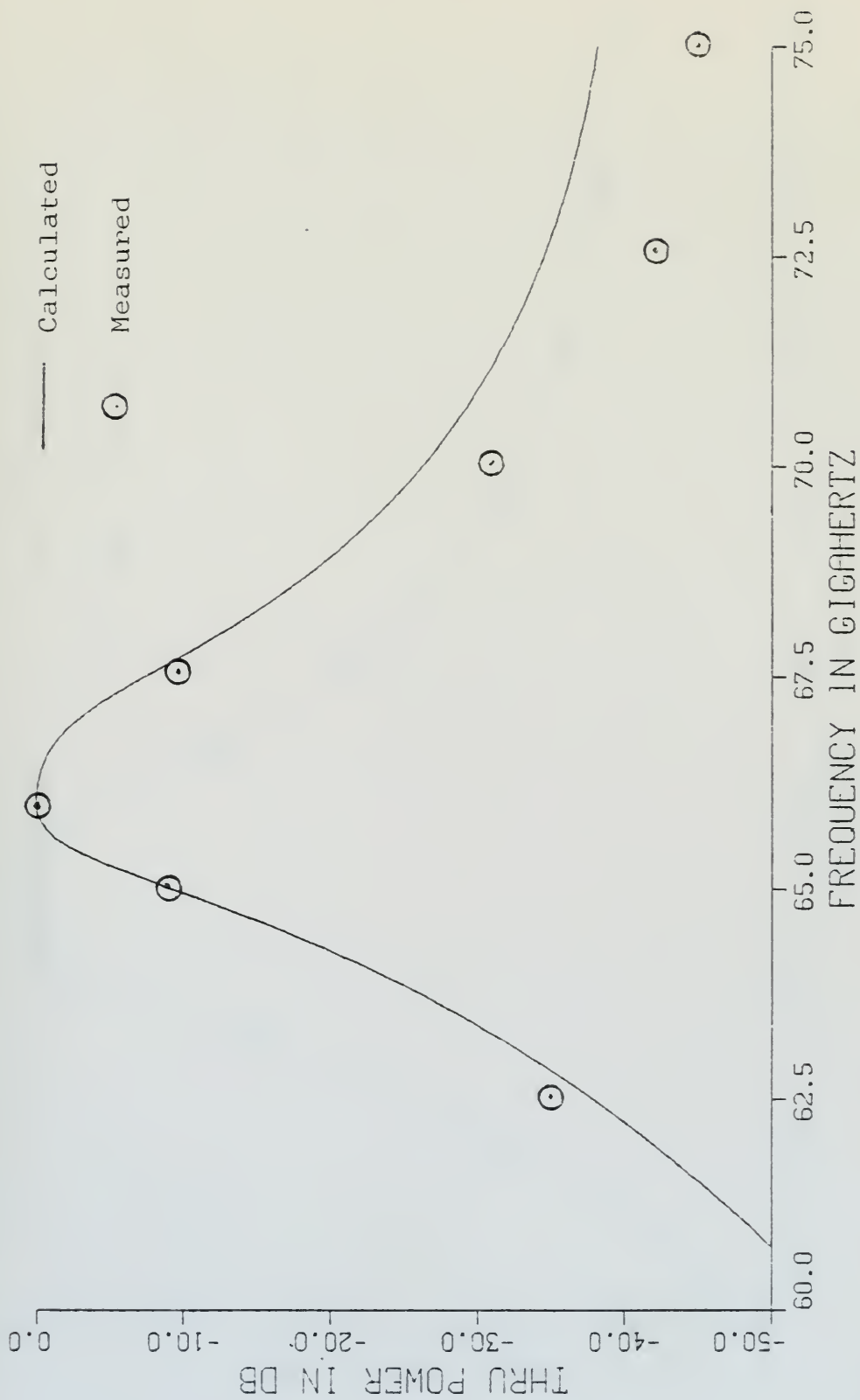




#### FILTER 4.

Fig. IV-4. Calculated and Measured Insertion Loss of Fin-line #4

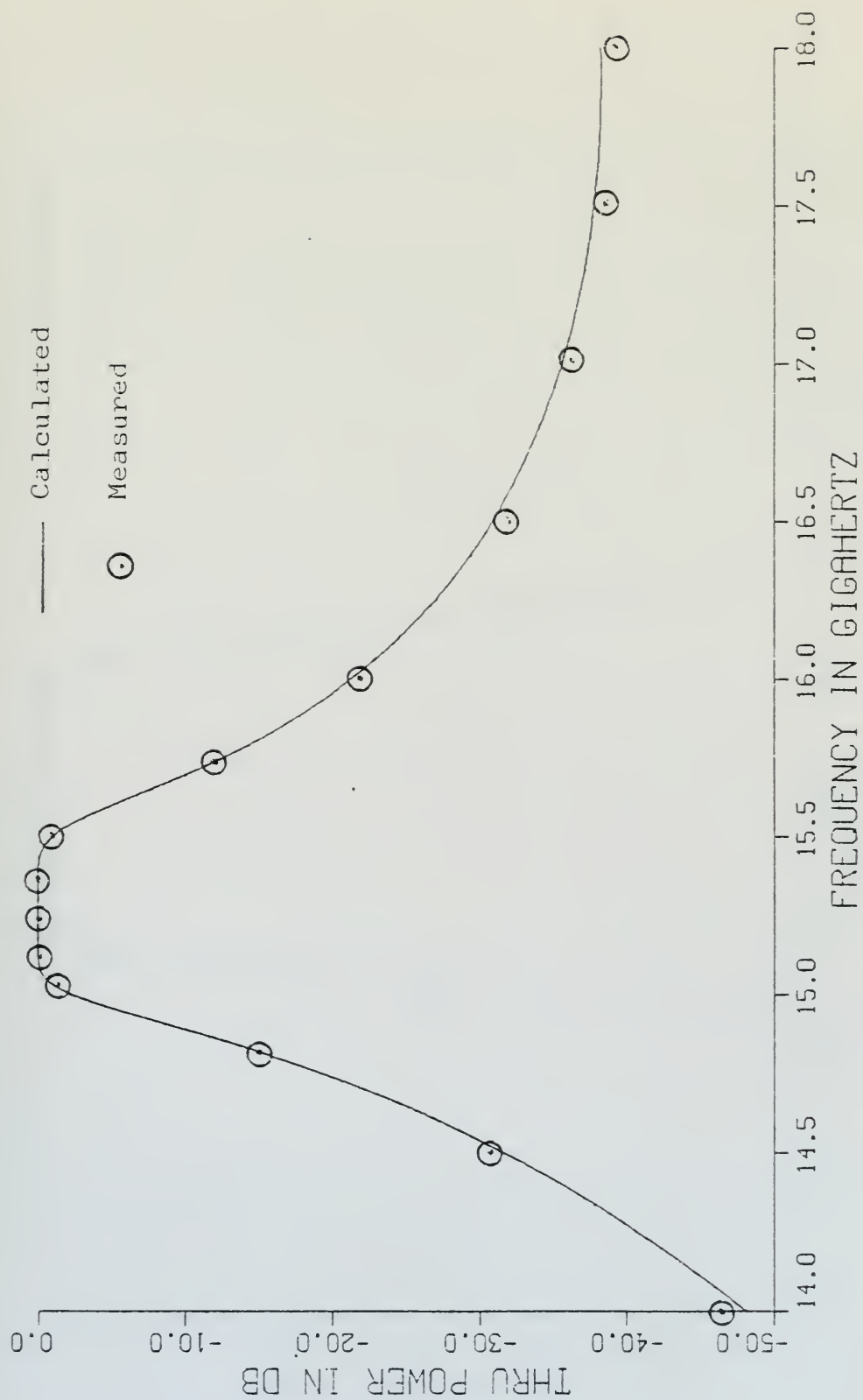




## FILTER 5.

Fig. IV-5. Calculated and Measured Insertion Loss of Pin-line #5



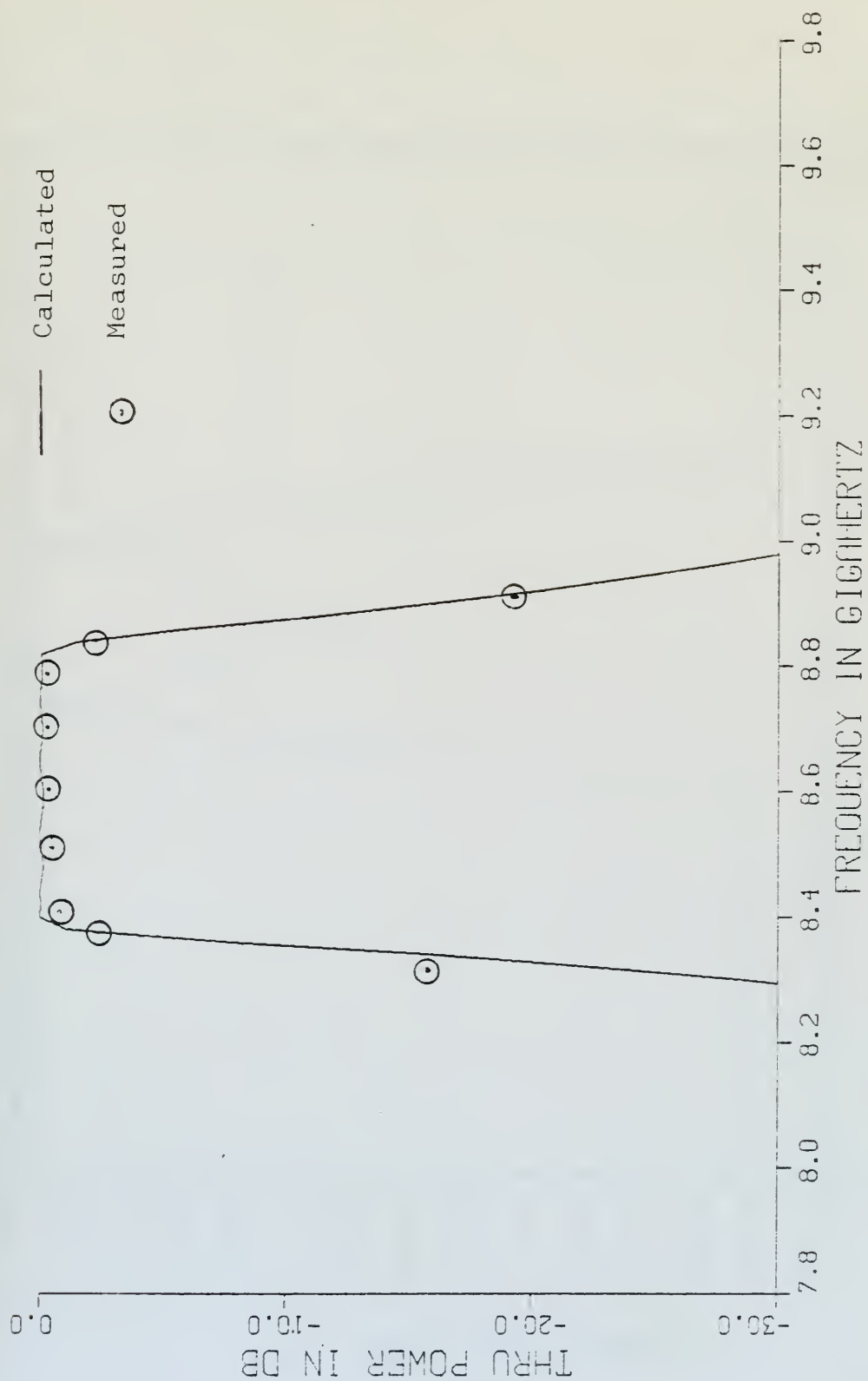


## FILTER 6.

Fig. IV-6. Calculated and Measured Insertion Loss of Fin-line #6







## FILTER 7.

Fig. IV-6. Calculated and Measured Insertion Loss of Fin-line #7



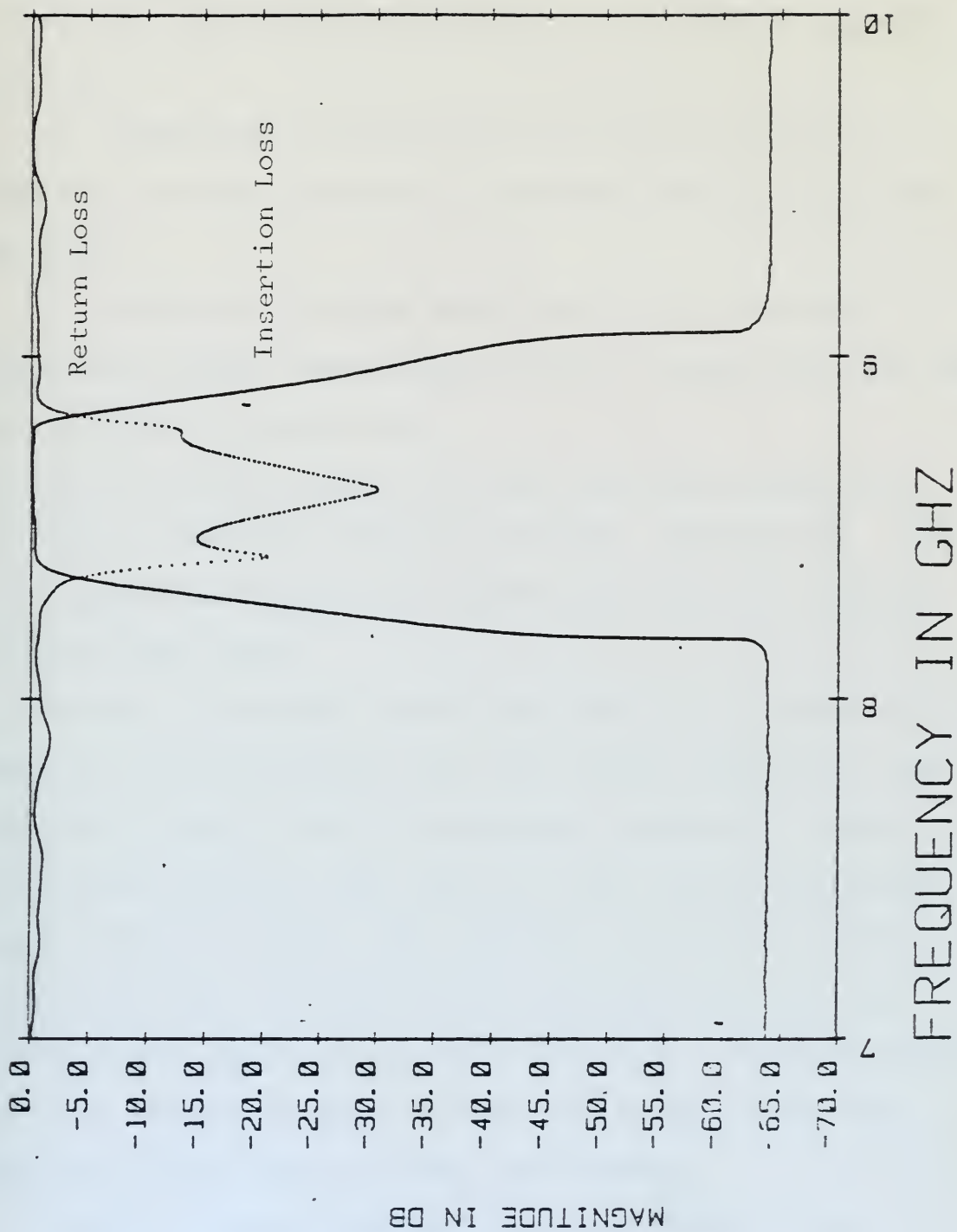


Fig. IV-8. Filter #7 Experimental Curve



Secondly, difficulties associated with the fabrication of the Class III filters suggests the need for an improved construction technique. Any new such technique needs to address the two major shortcomings of the method employed. These are:

- 1) Difficulty in longitudinally aligning the two separate fin-line sections to maintain symmetry about the  $x=0$  axis.

- 2) Persistent problems associated with inadequate electrical contact between the filter's conducting fins and the waveguide's broad walls.

Failure to correct either of these recurring tendencies resulted in severely reduced electrical performance. Thus, the original motivation for developing Class III filters may have been false.

Thirdly, dielectric substrates should be tapered. For example, the narrow band Class III filter (filter #1) was originally constructed on rectangular dielectric slabs. The entire insertion loss curve of this filter exhibited about 12 dB of ripple. The insertion loss data points plotted are for the same filter, but with the addition of dielectric ramps on all four slab ends. Passband ripple was thus reduced to about 0.1 dB, and ripple along the rejection skirts was no longer noticeable.

Finally, from an applications view point, it is important to realize that the strip widths exhibit a



correlation to passband ripple. That is, as the ripple is decreased, the fin-line strip dimension decreases. Strip width may be increased by either specifying a larger ripple, or by forcing additional resonators by requiring sharper rejection skirts. Wider strip widths are preferable simply because of achievable mechanical tolerances, and structural integrity.





## V. CONCLUSIONS AND RECOMMENDATIONS

The numerical analysis technique employed by the authors will always produce a result. The question is whether this result has any correlation to the physical world. It was found that this numerical analysis yields values essentially identical to those obtained by Shih [Ref. 2], who employed a completely different approach, and evaluated entirely different expressions. This suggests that both approaches are valid. Furthermore, the good agreement between all predicted filter responses and filter performance strongly suggests that the procedure applied was theoretically sound, and properly executed.

The CAD program produced by this study is not an end in itself, but a design tool. It should be used to answer a number of design questions. It is recommended that an organized study be conducted to determine the following:

- 1) Under what conditions is the center-line structure preferable to a bilateral structure?
- 2) For the bilateral fin-line, what determines the optimal transverse fin-line location?
- 3) Are there optimal values for the relative permittivities in the Class II and Class III filter designs?
- 4) How sensitive is filter response to dimensional tolerances?



5) Does the current filter design meet engineering requirements, or is the use of a design/response optimization routine justified?

6) To what extent can the number of modes retained in the numerical analysis be reduced without adversely reducing accuracy?

Finally, to determine more accurately the degree of correspondence between simulated and physical filter performance it will be necessary to construct higher quality devices. In particular, the fin-line structure should be produced by photo-etching techniques to minimize dimensional errors.



# APPENDIX A

## REGION I EIGENMODES

The solution to the general wave equation for an EM wave in a guide with dissimilar dielectric zones, as shown in Fig. II-1 (Region I), is found in a manner similar to that for a simple waveguide. However, in this instance, the eigenvalues for the propagation numbers are not explicitly expressible. Instead, a pair of transcendental equations is found (A.1 and A.2) which must be solved simultaneously to determine each eigenvalue.

For incident  $TE_{mo}$  ( $m$  odd) modes, the  $Z$  component of the magnetic field ( $H_z$ ) in the wave guide will have a value of zero along the  $x=0$  plane. It is convenient, therefore, to impose the condition of a "magnetic wall" along  $x=0$ , on which a boundary condition is that

$$H_z \Big|_{x=0} = 0.$$

By referring to the geometry of the waveguide depicted in Fig. II-2, we can write the form of the  $E_y$  fields as:

$$\phi_{lm} = A_m \sin k_{lm}x + B_m \cos k_{lm}x$$

$$\phi_{um} = C_m \sin k_{um}x + D_m \cos k_{um}x .$$



At the magnetic wall,  $x=0$ , the boundary condition imposed is:

$$[-j\omega\mu H_z = \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}]_{x=0} = 0 .$$

But since  $(\frac{\partial}{\partial y}) = 0$  for all fields, we can write:

$$[\frac{\partial E_y}{\partial x}]_{x=0} = 0 = [K_{1m} A_m \cos k_{1m} - k_{1m} B_m \sin k_{1m} x]_{x=0} .$$

Whence,  $A_m = 0$ .

The second boundary condition to be satisfied is that:

$$[E_y]_{x=a} = 0 .$$

So that:

$$C_m \sin k_{um} a + D_m \cos k_{um} a = 0 .$$

Whence,

$$D_m = -C_m \tan k_{um} a .$$

Therefore, the  $E_y$  fields in Region I is given by:





$$\phi_{lm} = B_m \cos k_{lm} x; \quad 0 \leq x \leq d$$

$$\phi_{um} = C_m [\sin k_{um} x - \tan k_{um} a \cos k_{um} x]; \quad d \leq x \leq a.$$

Or, employing a trigonometric identity,  $E_{yu}$  may be expressed as:

$$\phi_{um} = C_m \frac{\sin k_{um} (a-x)}{\cos k_{um} a} = \Omega_m \sin k_{um} (a-x).$$

Finally,  $E_{y1} = E_{yu}$  at the boundary of the two zones. That is:

$$B_m \cos k_{lm} d = \Omega_m \sin k_{um} (a-d).$$

From which:

$$B_m = \Omega_m \frac{\sin k_{um} (a-d)}{\cos k_{lm} d}.$$

Likewise, the Z component of the magnetic field must be continuous across the boundary. So that:

$$[H_{z1} = H_{zu}]_{x=d}.$$



Whence:

$$B_m k_{lm} \sin k_{lm} d = \Omega_m \cos k_{um} (a-d).$$

Substituting for  $B_m$  above, we find that:

$$k_{lm} \tan k_{lm} d = k_{um} \cot k_{um} (a-d). \quad (A.1)$$

The second equation which the propagation numbers must satisfy is the usual dispersion relation for an EM wave propagation through a dielectric discontinuity [Ref. 4].

$$k_{lm}^2 = k_{um}^2 - k_o^2 (\epsilon_u - \epsilon_l). \quad (A.2)$$

The amplitudes of the eigenmodes may be determined by applying the orthogonality property of the modes. That is, trigonometric identities may be used to rewrite the expressions for the eigenmodes as follows:

$$\phi_{lm} = B_m \cos k_{lm} x = \Lambda_m \cos k_{lm} x; \quad 0 \leq x \leq d$$

$$\phi_{um} = \Omega_m \sin k_{um} (a-x).$$



The orthogonality of these modes is exploited by integrating the product of mode pairs across the width of the guide.

$$\int_0^a \phi_m \phi_n dx = \delta_{mn}$$

so that,

$$\int_0^d \Omega_n \cos^2 k_{lm} x + \int_0^a \Omega_n \sin^2 k_{um} (a-x) dx = 1 .$$

Whence,

$$\Omega_m = \left[ \left( \frac{\sin^2 k_{um} (a-d)}{\cos^2 k_{lm} d} \right) \left( \frac{d}{2} + \frac{\sin^2 k_{lm} d}{4 k_{lm}} \right) \right.$$

$$\left. + \left( \frac{(a-d)}{2} - \frac{\sin^2 k_{um} (a-d)}{4 k_{um}} \right) \right]^{-1/2}$$

$$\Lambda_m = \Omega_m \frac{\sin k_{um} (a-d)}{\cos k_{lm} d} .$$



## APPENDIX B

### DERIVATION OF EXPRESSIONS FOR H-MATRIX ELEMENTS

The elements of the H-Matrix are defined by:

$$H_{mn} = \int_0^a \phi_n \psi_m dx$$

where

$$\phi_n = \begin{cases} \Lambda_n \cos k_{ln} x & : 0 \leq x \leq d \\ \Omega_n \sin k_{un}(a-x) & : d \leq x \leq a \end{cases} \quad (\text{II.A.1})$$

$$\psi_m = \begin{cases} \left(\frac{2}{d}\right)^{1/2} \cos k_{lm} x & : 0 \leq x \leq d \\ \left(\frac{2}{a-d}\right)^{1/2} \sin k_{um}(a-x) & : d \leq x \leq a \end{cases} \quad (\text{II.A.4})$$

We have therefore:

$$\begin{aligned} H_{mn} = & \int_0^d (\Lambda_n \cos k_{ln} x) \left(\frac{2}{d}\right)^{1/2} (\cos k_{lm} x) dx \\ & + \int_d^a (\Omega_n \sin k_{un}(a-x)) \left(\frac{2}{a-d}\right)^{1/2} (\sin k_{um}(a-x)) dx \end{aligned}$$





$$H_{mn} = \Lambda\left(\frac{2}{d}\right)^{1/2} \left[ \frac{\sin(k_{ln} - k_{Lm})d}{2(k_{ln} - k_{Lm})} + \frac{\sin(k_{ln} + k_{Lm})d}{2(k_{ln} + k_{Lm})} \right. \\ \left. - \Omega_m\left(\frac{2}{a-d}\right) \left[ \frac{\sin(k_{un} + k_{Um})(a-d)}{2(k_{un} + k_{Um})} - \frac{\sin(k_{un} - k_{Um})(a-d)}{2(k_{un} - k_{Um})} \right] \right].$$

$$H_{mn} = A_n \left(\frac{2}{d}\right)^{1/2} [(-1)^m \cos k_{1n} d] \left[ \frac{k_{1m}}{k_{1n}^2 - k_{1m}^2} \right] \quad (\text{II.B.2})$$

$$+ \Omega_m \left(\frac{2}{a-d}\right)^{1/2} [(-1)^m \sin k_{un} (a-d)] \left[ \frac{k_{Um}}{k_{un}^2 - k_{Um}^2} \right] .$$



## APPENDIX C

### JUNCTION SCATTERING MATRIX

Consider the waveguide discontinuity as a two-port junction problem, as represented schematically in Fig. II-3, where  $(a_n^+, a_n^-)$  and  $(b_n^-, b_n^+)$  are the amplitudes of the incident and scattered modal fields in Region I and II, respectively.

The electric field is a single-valued function of  $Z$ . Hence, at the junction boundary,  $Z=0$ , we can write:

$$\sum_{n=1}^{\infty} a_n^+ \phi_n + \sum_{n=1}^{\infty} a_n^- \phi_n = \sum_{n=1}^{\infty} b_n^+ \psi_n + \sum_{n=1}^{\infty} b_n^- \psi_n. \quad (C.1)$$

Similarly, the relationship for the  $x$ -component of the magnetic field,  $H_x$ , is:

$$\begin{aligned} & \sum_{n=1}^{\infty} Y_n^I a_n^+ \phi_n - \sum_{n=1}^{\infty} Y_n^I a_n^- \phi_n \\ &= \sum_{n=1}^{\infty} Y_n^{II} b_n^+ \psi_n - \sum_{n=1}^{\infty} Y_n^{II} b_n^- \psi_n. \end{aligned} \quad (C.2)$$



To utilize the orthonormality of the eigenmodes, we multiply C.1 by  $\frac{\psi}{m}$  and integrate across the waveguide.

$$\sum_{n=1}^{\infty} (a_n^+ + a_n^-) \int_0^a \phi_n \psi_m dx = \sum_{n=1}^{\infty} (b_n^+ + b_n^-) \int_0^a \psi_n \psi_m dx$$

$$\sum_{n=1}^{\infty} (a_n^+ + a_n^-) H_{mn} = b_m^+ + b_m^- \quad . \quad (C.3)$$

We define the values  $H_{mn}$  as:

$$H_{mn} = \int_0^a \phi_n \psi_m dx.$$

Likewise, multiplying equation C.2 by  $\phi_m$  and integrating yields:

$$Y_m^I (a_m^+ - a_m^-) = \sum_{n=1}^{\infty} (b_n^+ - b_n^-) Y_n^{II} H_{nm} \quad . \quad (C.4)$$

The wave impedances of the normal modes,  $Y_n$ , may be represented as diagonal matrices, the values  $H_{mn}$  as an  $m$  by  $n$  matrix, and the amplitudes of the normal modes as vectors. Equations C.3 and C.4 may then be expressed as follows (subscripts have been omitted for simplicity).



$$[H] [a^+ + a^-] = [b^+ + b^-] \quad (C.3.1)$$

$$[Y^I] [a^+ - a^-] = [H^T] [Y^{II}] [b^+ - b^-] . \quad (C.4.1)$$

C.3.1 is solved for  $[b^+]$ :

$$[b^+] = [H] [a^+ - a^-] - [b^-] .$$

Substituting  $[b^+]$  into C.4.1:

$$[Y^I + H^T Y^{II} H] [a^-] = [Y^I - H^T Y^{II} H] [a^+] + 2[H^T Y^{II}] [b^-] .$$

Whence,

$$\begin{aligned} [a^-] &= [Y^I + H^T Y^{II} H]^{-1} [Y^I - H^T Y^{II} H] [a^+] \\ &\quad + 2[Y^I + H^T Y^{II} H]^{-1} [H^T Y^{II}] [b^-] . \end{aligned} \quad (C.5)$$

Likewise, C.4.1 may be solved for  $[a^-]$  and this substituted into C.3.1 to yield:

$$\begin{aligned} [b^+] &= [I + H Y^I - H^T Y^{II}]^{-1} 2[H] [a^+] \\ &\quad - [I + H Y^I - H^T Y^{II}]^{-1} [I - H Y^I - H^T Y^{II}] [b^-] . \end{aligned} \quad (C.6)$$





But from standard scattering matrix notation with the values denoted as in Fig. II-3, we can also write:

$$\begin{bmatrix} a^- \\ b^+ \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a^+ \\ b^- \end{bmatrix}$$

or,

$$[a^-] = [S_{11}][a^+] + [S_{12}][b^-] .$$

(C.7)

$$[b^+] = [S_{21}][a^+] + [S_{22}][b^-] .$$

By comparing C.5 and C.6 with C.7, it is clear that:

$$[S_{11}] = [Y^I + H^T Y^{II} H]^{-1} [Y^I - H^T Y^{II} H]$$

$$[S_{12}] = 2[Y^I + H^T Y^{II} H]^{-1} [H^T Y^{II}] = [I - S_{11}]H^T \quad (C.8)$$

$$[S_{21}] = 2[I + H[Y^I]^{-1} H^T Y^{II}]^{-1} [H] = H[I + S_{11}]$$

$$[S_{22}] = [I + H Y^I^{-1} H^T Y^{II}]^{-1} [I - H Y^I^{-1} H^T Y^{II}] = -H[S_{11}]H^T .$$



## APPENDIX D

### SCATTERING MATRIX FOR A FINITE LENGTH SEPTUM

A generalized scattering matrix technique in a manner similar to that of Shih in [Ref. 3] is applied to obtain the two port scattering matrix for the finite septum.

Consider a  $TE_{m0}$  -type wave incident from Region I at the junction A. The field at this junction is comprised of the vector sum of all the eigenmodes in each region. Some of the energy will be reflected at the boundary, propagating in  $(\phi_m)$  modal fields in the minus Z direction. The remainder of the energy will be transmitted into Region II in  $(\psi_p)$  modal fields in the positive Z direction. After traveling a distance D, the transmitted modes encounter the second junction, B, where again some energy is reflected, and some transmitted. Multiple reflections of the modes between junctions A and B is inherently accounted for in the matrix manipulations which yield the scattering matrix for the finite septum.

In C a single junction was analyzed as a two-port scattering matrix,  $[S_A]$ . Each of the four elements of this scattering matrix,  $[S_{A11}]$ ,  $[S_{A12}]$ ,  $[S_{A21}]$ , and  $[S_{A22}]$ , is a matrix of infinite dimensions, corresponding to the infinite set of eigenmodes in both regions (equation C.8).

The junction B is identical to A, except for orientation. It may be shown, therefore, that the scattering matrix for



the isolated junction B is related to the isolated junction at A by the following:

$$[S_{A11}] = [S_{B22}]$$

$$[S_{A12}] = [S_{B21}] \quad .$$

The effects of the wave propagating (for propagating modes) or attenuating (for evanescent modes) along the strip length are accounted for by a transmission matrix,  $[T_D]$ , defined as:

$$[T_D] = \begin{bmatrix} [I] & [0] \\ [0] & [T] \end{bmatrix}$$

where  $[I]$  is the identity matrix,  $[0]$  is the null matrix, and  $[T]$  is a diagonal matrix of infinite size. The diagonal elements of  $[T]$  are:

$$T_{ii} = e^{-\gamma_{ii}D} \quad .$$



The combined effect of the single junction A followed by the transmission along the strip for a distance D is given by the scattering matrix  $[S'_A]$ .

$$[S'_A] = [T_D] [S_A] [T_D]$$

Finally, the net effect of the finite septum is determined as follows.

$$a^- = S'_{A11} a^+ + S'_{A12} b^+ \quad (D.1)$$

$$b^- = S'_{A21} a^+ + S'_{A22} b^+ \quad (D.2)$$

$$c^- = S_{B11} c^+ + S_{B12} d^+ \quad (D.3)$$

$$d^- = S_{B21} c^+ + S_{B22} d^+ \quad (D.4)$$

$$b^+ = c^- \quad (D.5)$$

$$c^+ = b^- \quad (D.6)$$

We define an equivalent matrix for the finite septum,  $[S_E]$ , by:

$$a^- = S_{E11} a^+ + S_{E12} d^+ \quad (D.7)$$

$$d^- = S_{E21} a^+ + S_{E22} d^+ \quad (D.8)$$





With the equalities given in equations D.5 and D.6, we substitute equation D.2 into D.3 to yield:

$$\begin{aligned}
 d^- = & [S'_{A21}][I - S_{B22} S'_{A11}]^{-1} [S_{B21}] a^+ \\
 & + [S'_{A22}][I - S_{B22} S'_{A11}]^{-1} [S_{B22} S'_{A12} + S'_{A22}] d^+.
 \end{aligned}
 \tag{D.9}$$

Likewise, we substitute equation D.4 into D.1 to yield:

$$\begin{aligned}
 a^- = & [S'_{A11} + S'_{A12}[I - S_{B11} S'_{A22}]^{-1} [S_{B11} S'_{A21}]] \\
 & + [S'_{A12}][I - S_{B11} S'_{A22}]^{-1} [S_{B12}] d^+.
 \end{aligned}
 \tag{D.10}$$

The matrices which are the elements of the equivalent scattering matrix may be written down by simply comparing equations D.9 and D.10 with equations D.7 and D.8.

$$S_{E11} = [S'_{A11}] + [S'_{A12}][I - S_{B11} S'_{A22}]^{-1} [S_{B11} S'_{A21}]$$

$$S_{E12} = [S'_{A12}][I - S_{B11} S'_{A22}]^{-1} [S_{B12}]$$

$$S_{E21} = [S'_{A21}][I - S_{B22} S'_{A11}]^{-1} [S_{B21}]$$



$$S_{E22} = [S'_{A21}][I - S_{B22} S'_{A11}]^{-1} [S_{B22} S'_{A12}] + [S'_{A22}] . \quad (D.11)$$



## APPENDIX E

### CASCADING SEVERAL FINITE LENGTH SEPTA

The fin-line filter is simply a series of finite length septa separated by transmission line sections. The net effect of the entire filter structure may be represented in a single "total" scattering matrix which accounts for the combined effects of each septa/transmission line section. This total scattering matrix is obtained by combining each septum equivalent matrix in a manner precisely analogous to that used in D to develop the equivalent matrix for a finite septum. That is, in D, expressions for the net effect of two discontinuities separated by a transmission line section were obtained (equation D.11). It is now necessary to express the net effect of two septa separated by a transmission line section. Consequently, the equivalent scattering matrix of two separated septa may be found by use of the equation D.11, with the appropriate scattering matrices for the septa substituted for the junction scattering matrix. More than two septa are cascaded by repeated application of D.11. Due care must be exercised to assure that the propagation numbers used in the transmission matrix correspond to the appropriate wave number and region of waveguide propagation.



# APPENDIX F

## COMPUTER AIDED DESIGN PROGRAM

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THE000010
THE000020
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THE000400
THE000410
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THE000450
THE000460
THE000470
THE000480

FILTER DESIGN (FILDES) FORTRAN PROGRAM
BY KEITH B. ALEXANDER
AND STEVEN R. HAMEL

THE PURPOSE OF THIS PROGRAM IS TO DEVELOP FILTERS FOR WAVEGUIDE
STRUCTURES AND SIMULATE THE CHARACTERISTIC OF THIS FILTER THRU
A SPECIFIED FREQUENCY RANGE. THE USER HAS THE CHOICE OF EITHER
DESIGNING THE FILTER AND INPUTTING THE NECESSARY DIMENSIONS OR
THE USER CAN INPUT THE CHARACTERISTICS THAT THE FILTER SHOULD
HAVE AND THE COMPUTER WILL DESIGN THE FILTER. IN BOTH CASES THE
COMPUTER WILL OUTPUT THE CHARACTERISTICS OF THE FILTER THROUGH
A USER DESIGNATED FREQUENCY RANGE.

THE USER THEREFORE HAS TWO OPTIONS IN THIS PROGRAM TO DEVELOP A
FILTER USING THIS PROGRAM OR TO INPUT HIS OWN FILTER DESIGN.
IN EITHER CASE IT IS NORMALLY EASIER TO USE A PRECANNED INPUT
FILE RATHER THAN ENTERING IN EACH VARIABLE INTO THE COMPUTER.

TO DEVELOP A CANNED INPUT FILE FOR THE COMPUTER AIDED DESIGN OF
A FILTER ONE WOULD INPUT A FILE AS SHOWN BELOW:

FIL FILE (OR ANY NAME THE USER CHOOSES AND CAN REMEMBER)

1
10
1.143 .50663
1.00 1.6197
9.00 10.00
10.5 15.0
.50
8.00
100.0 41
0.50 12.0
-30.00 10.0
0.00

EXPLANATION OF PRECANNED FILE

DESIGN OPTION (1 = COMPUTER DESIGN, 0 = UMN DESIGN)
FILTER NUMBER FOR OUTPUT GRAPH
HALF WAVEGUIDE WIDTH AND DISTANCE FROM CENTER TO EDGE OF FILTER (CM)
DIELECTRIC CONSTANTS: INNER REGION; OUTER REGION
FREQUENCY PASSBAND OF FILTER IN GHZ BEGINNING AND END
PASSBAND CHARACTERISTIC IN GHZ AND AMOUNT OF LOSS IN DB
RIPPLE ACROSS THE PASSBAND IN DB
BEGINNING POINT IN GHZ FOR GRAPH OUTPUT
FREQ INTERVAL FOR POINTS AND NUMBER OF POINTS TO GRAPH

```





GRAPH TICK MARKS IN GHZ AND END POINT IN GHZ  
 DB LOW POINT AND INTERVAL FOR GRAPH  
 DB HIGH POINT FOR GRAPH

PRECANNED FILE FOR YOUR OWN FILTER DESIGN

DES1 FILE (OR ANY NAME THE USER CAN REMEMBER)

0 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0

0	10	0.247	0.444	0.247
3	0.247	2.1533		
	1.143	.508		
	1.00	2.22		
	8.0			
	100.0	41		
	.50	12.0		
	-30.00	10.00		
	0.00			

EXPLANATION FOR PRECANNED FILE

DESIGN OPTION (0 = OWN DESIGN; 1 = COMPUTER AIDED DESIGN)

NUMBER OF STRIPS IN YOUR DESIGN

FILTER NUMBER FOR OUTPUT GRAPH

STRIP WIDTHS (CM)

DISTANCE BETWEEN STRIPS (RESONATOR) WIDTHS (CM)

HALF WAVEGUIDE WIDTH AND DISTANCE FROM CENTER TO EDGE OF FILTER (CM)

DIELECTRIC CONSTANTS IN MIDDLE REGION AND OUTER REGION

FREQUENCY START POINT OF GRAPH IN GHZ

FREQUENCY INTERVAL BETWEEN SIMULATION POINTS (MHZ) AND NO. OF POINTS

FREQ INT FOR GRAPH TICK MARKS (GHZ) AND END POINT OF GRAPH (GHZ)

DB LOW POINT AND INTERVAL FOR GRAPH

DB HIGH POINT FOR GRAPH

USE OF PROGRAM

(NOTE: THIS PROGRAM SHOULD BE COMPILED WITH THE H COMPILER)  
 TO USE THIS PROGRAM WITH A PRECANNED FILE PROCEED AS FOLLOWS:

ENTER: DEFINE STORAGE IM

ENTER: I CMS

ENTER: GLOBAL TXILIB FORTMOD2 MOD2EEN IMSLDP

ENTER: FILEDEF 05 DISK FIL1 FILE

(OR ENTER): FILEDEF 05 DISK DES1 FILE

ENTER: FILEDEF 06 DISK RESULT FILE

ENTER: DISSPLA FILDES1

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 THE00500  
 THE00510  
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 THE00690  
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THE01370  
THE01380  
THE01390  
THE01400  
THE01410  
THE01420  
THE01430  
THE01440

THE RESULTS OF YOUR PROGRAM WILL BE IN ' RESULT FILE '  
TO GET A GRAPH OF THE OUTPUT:

ENTER: DISSPOP

AND FOLLOW THE NORMAL IBM PROCEDURE FOR GRAPH OUTPUTS.

SUBROUTINES USED IN THIS PROGRAM

GETDAT - USED TO GET NECESSARY DATA FROM THE USER WHEN  
THE USER IS USING THE COMPUTER AIDED DESIGN OPTION.

ENTDAT - USED TO GET NECESSARY DATA FROM THE USER WHEN  
THE USER HAS HIS OWN FILTER TO TEST.

DESIGN - USED TO DESIGN THE FILTER BASED ON USER REQUIREMENTS.

LEVY - FILTER SYNTHESIS SUBROUTINE USED TO DESIGN THE FILTER.

TREGAM - USED TO RETURN FREQUENCIES BASED ON INPUT WAVELENGTHS.

ZROCRS - USED TO FIND THE ZERO POINT OF A ROOT BASED ON BISECTION.

BETAFI - FINDS THE BETA VALUE FOR A DESIGNATED FREQUENCY.

COEFF - USED TO FIND THE REFLECTION COEFFICIENTS FOR DIFFERENT  
MODES FOR A DESIGNATED FILTER DESIGN.

DEC - USED AS A SUBPROGRAM TO 'COEFF' TO HELP FIND THE REFLECTION  
COEFFICIENTS FOR EACH MODE.

FILTER - PROGRAM USED TO DEVELOP THE S-MATRIXES BASED ON GIVEN  
FREQUENCIES.

BUILD - USED TO DEVELOP SEPARATOR AND RESONATOR WIDTHS.

ROOT - USED AS A SUBPROGRAM TO 'BUILD' TO FIND SEPARATOR AND  
RESONATOR WIDTHS.

PROPAG - USED TO DEVELOP THE PROPAGATION NUMBERS FOR EACH MODE.

SMATRI - USED TO DEVELOP THE S-MATRIX FOR EACH FREQUENCY.

MATWRI - USED TO OUTPUT THE VALUES OF MATRIXES.

CMMUL - COMPLEX MATRIX MULTIPLICATION SUBROUTINE.

CC





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CC CMSGUM - COMPLEX MATRIX SUMMATION SUBROUTINE.
CC PACMAN - USED TO CONDENSE THE CRITICAL ELEMENTS OF THE 30 BY 30
CC S-MATRIX INTO 5 BY 5 MATRICES.
CC CMSGUB - COMPLEX MATRIX SUBTRACTION SUBROUTINE.
CC CASCAD - SUBROUTINE USED TO CASCADE THE S-EQUIVALENT MATRICES DOWN
CC THE ENTIRE LENGTH OF A FILTER.
CC TRANSM - SUBROUTINE THAT DEVELOPS THE TRANSMISSION EFFECT ON THE
CC S-PARAMETERS FOR A GIVEN STRIP OR SEPARATOR LENGTH.
CC DSUM - USED TO SUM EQUIVALENT S-MATRIX PARAMETERS TOGETHER.
CC CMRNMU - COMPLEX MATRIX REAL NUMBER MULTIPLICATION.
CC CASCA - USED TO DEVELOP THE S-MATRIX FOR AN ENTIRE STRIP, OR COLLECT
CC OF STRIPS, DEPENDING ON INPUT PARAMETERS.
CC STEP3 - USED AS A SUBPROGRAM OF A FUNCTION TO DEVELOP THE S-MATRIX
CC PARAMETERS FOR A GIVEN STRIP.
CC STRIWI - USED TO DEVELOP THE ACTJAL STRIP WIDTHS AND RESONATOR WIDTHS
CC LEQTLIC - LINEAR EQUATION SOLVER, FROM IBM LIBRARY.
CC FUNCTIONS USED IN THIS PROGRAM:
CC TCHEBY - USED TO RETURN TCHEBYSHEV COEFFICIENTS AS A SUBPROGRAM OF
CC LEVY, IN FILTER DESIGN.
CC FCT1 - FINDS THE ZERO POINT FOR FREQUENCY CROSSINGS.
CC SFL - USED TO FIND S-MATRIX COEFFICIENTS FOR VARIOUS STRIP WIDTHS.
CC SUBROUTINES DESIGN, LEVY, ZROCRS, COEFF, DEC, FILTER, BUILD, ROOT,
CC CASCA, STEP3, AND THE FUNCTIONS ARE BASED ON ORIGINAL WORK DONE
CC BY DR. YI-CHI SHIH IN HIS DOCTORAL DISSERTATION FOR FINLINE
CC STRUCTURES IN WAVEGUIDES.
CC VARIABLES USED THROUGHOUT THE ENTIRE PROGRAM
CC FREQ FREQUENCY IN GIGAHERTZ
CC FRQ FREQUENCY IN GIGAHERTZ

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C	FRESTE	NUMBER OF	FREQUENCY	STEPS FOR	SIMULATION	THE01930
C	FRQINT	FREQUENCY	INTERVAL	IN MEGAHERTZ	FOR OUTPUT	THE01940
C	FRQEND	END FREQUENCY	IN GIGAHERTZ	FOR GRAPH		THE01950
C	FRQINT	FREQUENCY	INTERVAL	FOR GRAPH	TICK MARKS	THE01960
C	TEMP	TEMPORARY	VARIABLE			THE01970
C	A	HALF OF	THE WAVEGUIDE	WIDTH IN	CENTIMETERS	THE01980
C	C	DISTANCE	FROM THE	EDGE OF	THE FILTER	TO THE WAVEGUIDE
C	D	WALL IN	CENTIMETERS			THE01990
C		DISTANCE	FROM THE	CENTER OF	THE WAVEGUIDE	TO THE EDGE
C	NSTRIP	OF THE	FILTER IN	CENTIMETERS		THE02000
C	NOS	NUMBER OF	CONDUCTING	STRIPS	ON THE	DIELECTRIC SLAB
C	NOR	NUMBER OF	CONDUCTING	STRIPS		THE02010
C	COSTWI	CONDUCTING	STRIP WIDTH	(VECTOR)		THE02020
C	DIBEC	DISTANCE	BETWEEN	CONDUCTING	STRIPS (VECTOR)	THE02030
C	ERU	RELATIVE	DIELECTRIC	CONSTANT	FOR THE	UPPER REGION
C	ERL	MAGNETIC	DIELECTRIC	CONSTANT	FOR THE	LOWER REGION
C	UO	PERMEABILITY	(CONSTANT)			THE02040
C	W	FREQUENCY	IN RADIANS			THE02050
C	LAM	FREE SPACE	WAVELENGTH			THE02060
C	PI	CONSTANT	PI			THE02070
C	PI	MODES	THAT ARE	THE	USER WANTS	TO TRY (UP TO 30)
C	NPMODE	NUMBER OF	MODES THAT	ARE	USED	IN THE CENTER REGION
C	T1	TEMPORARY	VARIABLE			THE02130
C	X1	TEMPORARY	FOR PROPAGATION	TERMS		THE02140
C	T2	TEMPORARY	FOR PROPAGATION	TERMS		THE02150
C	TREQ1	VARIABLE	FOR PROPAGATION	TERMS		THE02160
C		NUMERICAL	VALUES IN	THE	TRANSSCENDENTAL	EQUATION USED TO DETERMIN
C	TREQ2	THE WAVE	NUMBERS	IN THE	VARIOUS	REGIONS OF THE WAVEGUIDE
C	ERRREQ	SAME, BUT	EVALUATED	AT X2		THE02210
C	X3	PRECISION	REQUIREMENTS	FOR	DETERMINING	THE WAVE NUMBERS
C	KA	TEMPORARY	VARIABLE	CONTAINING	WAVE	NUMBERS IN REGION 1 (LOWER)
C	KD	RESULTANT	VECTOR	CONTAINING	WAVE	NUMBERS IN REGION 1 (UPPER)
C	KE	RESULTANT	VECTOR	CONTAINING	WAVE	NUMBERS IN REGION 2 (LOWER)
C		UPPER)				THE02270
C	KKKD	TEMPORARY	VARIABLE			THE02280
C	KKKA	TEMPORARY	VARIABLE			THE02290
C	NPMODE	TEMPORARY	MODES THAT	ARE	CONSIDERED	IN REGION 2 JPPER
C	Y1	IMPEDANCE	VECTOR	FOR	REGION 1	
C	Y2	IMPEDANCE	VECTOR	FOR	REGION 2	
C	GAMMA1	PROPAGATION	VECTOR	FOR	REGION 1	
C	GAMMA2	PROPAGATION	VECTOR	FOR	REGION 2	
C	H	SPACE	MAPPING	MATRIX		THE02350
C	YREG1	IMPEDANCE	MATRIX	FOR	REGION 1	
C	YREG2	IMPEDANCE	MATRIX	FOR	REGION 2	
C	S11	SCATTERING	PARAMETER			THE02370
C	S12	SCATTERING	PARAMETER			THE02380
C						THE02390
C						THE02400





LINE	STATEMENT	ADDRESS
1	SCATTERING PARAMETER MATRIX	THE02410
2	SCATTERING PARAMETER MATRIX	THE02420
3	TEMPORARY VARIABLE USED TO DEFINE H	THE02430
4	TEMPORARY VARIABLE USED TO MULTIPLY TWO MATRICES	THE02440
5	TEMPORARY MATRIX USED TO MULTIPLY TWO MATRICES	THE02450
6	OUTPUT OF MATRIX MULTIPLICATION	THE02460
7	SUMMATION INDEX FOR MATRIX MULTIPLICATION	THE02470
8	TEMPORARY MATRIX USED IN MATRIX SUBTRACTION	THE02480
9	TEMPORARY MATRIX USED IN MATRIX SUBTRACTION	THE02490
10	OUTPUT MATRIX FOR MATRIX SUBTRACTION	THE02500
11	SUMMATION INDEX FOR MATRIX SUBTRACTION	THE02510
12	TEMPORARY MATRIX FOR MATRIX ADDITION	THE02520
13	TEMPORARY MATRIX FOR MATRIX ADDITION	THE02530
14	OUTPUT MATRIX FOR MATRIX ADDITION	THE02540
15	SUMMATION INDEX FOR MATRIX ADDITION	THE02550
16	TEMPORARY MATRIX FOR MATRIX ADDITION	THE02560
17	TEMPORARY MATRICES USED IN CASCAD SUBROUTINE	THE02570
18	TEMPORARY MATRICES USED IN CASCAD SUBROUTINE	THE02580
19	TEMPORARY MATRICES USED IN CASCAD SUBROUTINE	THE02590
20	TEMPORARY MATRICES USED IN TRANSM SUBROUTINE	THE02600
21	TRANSMISSION MATRIX FOR S12	THE02610
22	TRANSMISSION MATRIX FOR S21	THE02620
23	VECTOR USED TO PASS GAMMA VECTORS FOR ALL REGIONS	THE02630
24	VARIABLE USED TO PASS STRIP WIDTHS AND DISTANCES	THE02640
25	SUMMATION INDEX	THE02650
26	TEMPORARY MATRICES USED FOR NETWORK COMBINATION OF MATRICES	THE02660
27	IDENTITY MATRIX	THE02670
28	SUMMATION INDEX FOR NETWORK COMBINATIONS	THE02680
29	COMPLEX *16 SM11(5,5), SM12(5,5), SM21(5,5), SM22(5,5)	THE02690
30	COMPLEX *16 S11(30,30), S12(30,30), S21(30,30), S22(30,30)	THE02700
31	COMPLEX *16 SE11(30,30), SE12(30,30), SE21(30,30), SE22(30,30)	THE02710
32	COMPLEX *16 ST11(30,30), ST12(30,30), ST21(30,30), ST22(30,30)	THE02720
33	COMPLEX *16 SS11(5,5), SS12(5,5), SS21(5,5), SS22(5,5)	THE02730
34	COMPLEX *16 KA(30), KD(30), KE(30), Y1(30), Y2(30)	THE02740
35	COMPLEX *16 GAMMA1(30), GAMMA2(30), B(30), CC(30,30)	THE02750
36	COMPLEX *16 X(30,30), Y(30,30), Z(30,30), AX(30,30)	THE02760
37	COMPLEX *16 XXX(30,30), YYY(30,30), ZZZ(30,30)	THE02770
38	COMPLEX *16 XX(30,30), YY(30,30), Z(30,30)	THE02780
39	COMPLEX *16 XY(30,30), YX(30,30), SB1(5), SB2(5)	THE02790
40	COMPLEX *16 XERL, UO, PI, W, D, LAM, A, C, COSTW(20), DIBEC(19)	THE02800
41	REAL *8 FREINT, DU(20), HW(20), XDB, RDB, YLOW, YSTEP, YHIGH	THE02810
42	REAL *8 F1, F2, FR, FREQ, FO, SO, RH, COE(20), TEM, FRQ, FRQINT, FRQEND	THE02820
43	REAL PLCTX(500), PLOTY(500)	THE02830
44	INTEGER NMODES, NPMODE, NSTRIP, FRESTE, WHIWAY, FILNO	THE02840
45		THE02850
46		THE02860
47		THE02870
48		THE02880



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C FIRST GET INFORMATION FROM THE USER
C
11 WRITE(6,11)
12 FORMAT(1) ENTER 1 IF YOU WANT THE COMPUTER TO DESIGN AND TEST ',/,
13 8. A FILTER FOR YOU OR "0" IF YOU WANT TO ENTER YOUR OWN DESIGN. ',/,
14 READ(5,*) WHIWAY
15 IF(WHIWAY.EQ.1) GO TO 14
16 CALL ENTDAT(NOS,NOR,COSTWI,DIBECs,A,D,ERU,ERL,FREQ,FRQINT,FRQEND,
17 PI,FRESTE,C,NMODES,NPMODE,FREINT,FILNG,YLOW,YSTEP,YHIGH)
18 NSTRIp = NOS
19 GO TO 15
20 CALL GETDAT(A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,FREINT,FRESTE,
21 8PI,C,NMDES,NPMODE,FRQINT,FKQEND,FILNO,YLOW,YSTEP,YHIGH)
22
C NOW CALCULATE THE NUMBER OF STRIPS FOR THE REQUIRED FILTER
C
23 CALL DESIGN(DD,WW,F1,F2,FR,XDB,RDB,ERU,ERL,F0,SO,RH,COE,A,D,PI,
24 NMDES,NPMODE,NOS,NOR)
25 CALL STRIWI(NOS,NOR,DD,WW,COSTWI,DIBECs,NSTRIP)
26 FRQ = FREQ
27 WRITE(6,21) NOS, NOR
28 2143 FORMAT(//,1 HERE ARE THE ',13,1 CONDUCTING STRIP WIDTHS ',/,
29 8. AND THE ',13,1 RESONATOR WIDTHS ',//)
30 DO 1567 JI=1,NSTRIP
31 WRITE(6,1578) COSTWI(JI),DIBECs(JI),NOS,NOR
32 1578 FORMAT(2F15.8,2I3)
33 1567 CONTINUE
34 WRITE(6,1599)
35 1599 FORMAT(1 LISTED BELOW IS THE POWER TRANSMITTED THRU YOUR ',/,
36 8. FILTER FOR EACH RESPECTIVE FREQUENCY POINT. '//)
37 DO 20 I = 1,FRESTE
38 LAM = 29.97925/FREQ
39 CALL TREQ(PI,A,LAM,NMODES,D,KA,KD,KE,NPMODE,ERU,ERL)
40
C GET THE PROPAGATION TERMS FOR EACH REGION
C
41 W = 2.0*PI*FREQ
42 UO = 4.0*PI
43 CALL PROPAG(KA,KE,GAMMA1,Y1,GAMMA2,Y2,PI,LAM,ERU,ERL,W,UO,
44 NMDES,NPMODE)
45
C DEVELOP THE SCATTERING MATRIX FOR THE FIRST STRIP EDGE
C
46 CALL SMATRI(SM11,SM12,SM21,SM22,KA,KD,KE,A,D,NMODES,Y1,Y2
47 ,NPMODE,GAMMA2,SB1,SB2,GAMMA1)
48
C NOW CASCADE THE MATRIX TO GET THE FILTER CHARACTERISTICS

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THE02900
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THE02940
THE02950
THE02960
THE02970
THE02980
THE02990
THE03000
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THE03020
THE03030
THE03040
THE03050
THE03060
THE03070
THE03080
THE03090
THE03100
THE03110
THE03120
THE03130
THE03140
THE03150
THE03160
THE03170
THE03180
THE03190
THE03200
THE03210
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THE03260
THE03270
THE03280
THE03290
THE03300
THE03310
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THE03330
THE03340
THE03350
THE03360

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C      CALL CASCAD(SM1,SM12,SM21,SM22,SB1,SB2,COSTWI,DIBEC,S,
C      NMODES,NSTRIP,SS1,SS12,SS21,SS22)
      PLOTX(1) = 20.0*DLOG10(CDABS(SS21(1,1)))
      PLOTX(1) = FREQ
      TEM = (CDABS(SS1(1,1)))**2.0 + (CDABS(SS12(1,1)))**2.0
      FREQ = (FREQ + (FREQ/1000.0))
      WRITE(6,322) PLOTX(1),PLOTX(1),TEM
322 FORMAT(1. DB LOSS, FREQ IN GHZ, ENERGY CHECK ,F12.6 , 4X,F8.4,4X,
8F6.4)
20 CONTINUE
   CALL COMPRS
   CALL MEDBUF
   CALL NOCHECK
   CALL BLOWUP(1.0)
   CALL PAGE(1.0, 8.5)
   CALL PHYSOR(2.25,2.50)
   CALL GRACE(0.0)
   CALL AREA2D(7.25,4.25)
   CALL XNAME('FREQUENCY IN GIGAHERTZ', 100)
   CALL YNAME('THRU POWER IN DB', 100)
   CALL GRAF(FREQ,FRQINT,FRQEND,YLOW,YSTEP,YHIGH)
   CALL CURVE(PLOTX,PLOTX,FRESTE,0)
   CALL ENDGR(0)
   CALL PHYSOR(1.5,1.25)
   CALL AREA2D(8.5,6.0)
   CALL HEIGHT(.2)
   CALL SWISSM
   CALL MESSAGE('FILTER $',100,1.4,0.30)
   CALL REALNO(FILNO,0,2.5,.30)
   CALL ENDPL(0)
   CALL DONEPL
   STOP
   END

SUBROUTINE GETDAT(A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,FREINT,FRESTE,
8PI,C,NMDES,NPMODE,FRQINT,FRQEND,FILNO,YLOW,YSTEP,YHIGH)
THE PURPOSE OF THIS SUBROUTINE IS TO GET THE INFORMATION
FROM THE USER NECESSARY FOR THIS PROGRAM TO RUN.

REAL *8 A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,P1,C,FREINT
REAL *8 FRQINT,FRQEND,YLOW,YSTEP,YHIGH,BP
REAL NMDES
INTEGER FRESTE,NMDES,NPMODE,FILNO

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THE03370
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C  TELL USER THE PURPOSE OF THIS PROGRAM AND NECESSARY GENERAL COMMENTS
C
C 300  WRITE (6,300)
      FORMAT(' THIS IS A PROGRAM USED TO DESIGN FILTERS. ',/,
8.  ' YOU WILL BE PROMPTED FOR THE REQUIRED INPUTS. ')
C
C 3001 WRITE (6,3001)
      FORMAT(' ENTER THE FILTER NUMBER FOR YOUR GRAPH. ')
      READ (5,*) FILNO
      WRITE (6,350) FILNO
      FORMAT(5X,I5,/)
C
C 301  WRITE (6,301)
      FORMAT(' INPUT HALF OF THE WAVE GUIDE WIDTH ',/,
8.  ' AND DISTANCE FROM THE CENTER OF THE GUIDE TO SEPTUM EDGE. ')
      READ (5,*) A,D
      WRITE (6,351) A,D
      FORMAT(5X,F12.8,5X,F12.8,/)
C
C 302  WRITE (6,302)
      FORMAT(' INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN ',/,
8.  ' FIRST THE CENTER OF THE GUIDE AND SEPTUM EDGE; ',/,
8.  ' AND SECOND BETWEEN SEPTUM WALL AND WAVEGUIDE WALL. ')
      READ (5,*) ERL,ERU
      WRITE (6,352) ERL,ERU
      FORMAT(5X,F12.8,5X,F12.8,/)
C
C  NMODES = 30
C
C  NOW TO GET THE REQUIREMENTS FOR THE FILTER
C
C 303  WRITE (6,303)
      FORMAT(' YOU WILL INPUT THE FILTER PARAMETERS ',/,
8.  ' ENTER THE BEGINNING AND END FREQUENCY FOR THE PASSBAND ',/,
8.  ' OF THE FILTER. ',)
      READ (5,*) F1,F2
      WRITE (6,353) F1,F2
      FORMAT(5X,F12.8,5X,F12.8,/)
      BP = 2.0*(F2-F1)/(F1+BP)
      F1 = F1*(1.0 - BP*BP)
C
C 304  WRITE (6,304)
      FORMAT(' NOW ENTER THE FREQUENCY AND DB DOWN FOR THE ',/,
8.  ' TAIL OF THE FILTER ',)
      READ (5,*) FR,RDB
      WRITE (6,354) FR,RDB
      FORMAT(5X,F12.8,5X,F12.8,/)
C

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THE03850
THE03860
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THE03990
THE04000
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THE04200
THE04210
THE04220
THE04230
THE04240
THE04250
THE04260
THE04270
THE04280
THE04290
THE04300
THE04310
THE04320

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C      WRITE (6,305)
305    FORMAT(' NOW ENTER THE RIPPLE IN DB ON THE TOP OF THE PASSBAND. ')
      READ (5,*) XDB
355    FORMAT(5X,F12.8,/)
C
      WRITE (6,306)
306    FORMAT(' THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH. ',/,
8      ' ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ. ')
      READ (5,*) FREQ
356    FORMAT(5X,F12.8,/)
C
      WRITE (6,307)
307    FORMAT(' ENTER THE FREQUENCY INTERVAL IN MHZ AND ',/,
8      ' THE NUMBER OF STEPS THAT YOU WOULD LIKE. ')
      READ (5,*) FREINT,FRESTE
357    FORMAT(5X,F12.8,5X,I5,/)
C
      WRITE (6,308)
308    FORMAT(' ENTER THE INTERVAL MARKS FOR THE GRAPH ',/,
8      ' AND THE END POINT FOR THE GRAPH. ')
      READ (5,*) FRQINT,FRQEND
358    FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE (6,309)
309    FORMAT(' ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS ',/,
8      ' FOR THE GRAPH IN DB. ')
      READ (5,*) YLOW, YSTEP
359    FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE (6,310)
310    FORMAT(' ENTER THE YAXIS HIGH POINT IN DB. ')
      READ (5,*) YHIGH
360    FORMAT(5X,F12.8,/)
C
C      DEFINING SEVERAL CONSTANTS
C
      PI = 3.14159265
      C = A - 0
C
      MODE = (C/A)*(FLOAT(NMODES))
      NPMODE = IFIX(MODE)

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THE04350
THE04340
THE04350
THE04360
THE04370
THE04380
THE04390
THE04400
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THE04580
THE04590
THE04600
THE04610
THE04620
THE04630
THE04640
THE04650
THE04660
THE04670
THE04680
THE04690
THE04700
THE04710
THE04720
THE04730
THE04740
THE04750
THE04760
THE04770
THE04780
THE04790
THE04800

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C      IF ((MODE-NPMODE).GT.0.5) NPMODE=NPMODE+1
C      RETURN
C      END
C
C      SUBROUTINE ENTDAT(NOS,NOR,COSTWI,DIBECs,A,D,ERU,ERL,FREQ,FRQINT,
C      8 FRQEND,PI,FRESTE,C,NMODES,NPMODE,FREINT,FILNO,YLOW,YSTEP,
C      8 YHIGH)
C
C      REAL *8 COSTWI(20),DIBECs(19),A,D,ERU,ERL,FREQ,FRQEND
C      REAL *8 PI,C,FREINT,FRQINT,YLOW,YSTEP,YHIGH
C      REAL MODE
C      INTEGER NOS,NOR,FRESTE,NMODES,NPMODE,FILNO
C
C      PI = 3.14159265
C      WRITE(6,100)
C      100 FORMAT(' THIS IS A PROGRAM USED TO TEST PRE-DESIGNED FILTERS. ',/,
C      8 ' YOU WILL BE PROMPTED FOR REQUIRED INPUTS. ',)
C
C      3001 WRITE(6,3001)
C      3001 FORMAT(' ENTER THE FILTER NUMBER FOR YOUR GRAPH. ')
C      READ(5,*) FILNO
C      150 WRITE(6,150) FILNO
C      150 FORMAT(' FILTER ',15,/)
C
C      101 WRITE(6,101)
C      101 FORMAT(' INPUT THE NUMBER OF STRIPS IN YOUR FILTER DESIGN. ')
C      READ(5,*) NCS
C      NOR = NOS - 1
C      151 WRITE(6,151) NOS,NOR
C      151 FORMAT(5X,' NOS = ',15,5X,' NOR = ',15,/)
C
C      102 WRITE(6,102)
C      102 FORMAT(' ENTER THE STRIP WIDTHS IN CENTIMETERS. ')
C      DO 103 I = 1,NOS
C      READ(5,*) COSTWI(I)
C      153 WRITE(6,153) I,COSTWI(I)
C      103 FORMAT(' STRIP NO ',13,' = ',F12.8)
C      CONTINUE
C
C      104 WRITE(6,104)
C      104 FORMAT(' ENTER THE RESONATOR WIDTHS IN CENTIMETERS. ')
C      DO 105 J = 1,NOR
C      READ(5,*) DIBECs(J)
C      155 WRITE(6,155) J,DIBECs(J)
C      105 FORMAT(' RESONATOR NO ',13,' = ',F12.8)
C      CONTINUE

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THE04810
THE04820
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THE04900
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THE04980
THE04990
THE05000
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THE05260
THE05270
THE05280

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C      WRITE(6,106)
      FORMAT(1,'INPUT HALF OF THE WAVEGUIDE WIDTH, CM, AND DISTANCE ',/,
106      8,' FROM THE CENTER OF THE WAVEGUIDE TO THE SEPTUM EDGE ',CM,'),
      READ(5,*) A,D
      WRITE(6,156) A,D
156      FORMAT(5X,F12.8,5X,F12.8,/)
C
      C = A - D
C
      WRITE(6,107)
      FORMAT(1,'INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN ',/,
107      8,' FIRST BETWEEN THE CENTER OF THE GUIDE AND SEPTUM EDGE ',/,
      8,' BETWEEN THE SEPTUM WALL AND WAVEGUIDE WALL. '),
      READ(5,*) ERL,ERU
      WRITE(6,157) ERL,ERU
157      FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE(6,108)
      FORMAT(1,'THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH. ',/,
108      8,' ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ '),
      READ(5,*) FREQ
      WRITE(6,158) FREQ
158      FORMAT(5X,F12.8,/)
C
      WRITE(6,109)
      FORMAT(1,'ENTER THE FREQUENCY INTERVAL IN MHZ AND ',/,
109      8,' THE NUMBER OF STEPS THAT YOU WOULD LIKE '),
      READ(5,*) FREINT,FRESTE
      WRITE(6,159) FREINT,FRESTE
159      FORMAT(5X,F12.8,5X,15,/)
C
      WRITE(6,110)
      FORMAT(1,'ENTER THE INTERVAL MARKS FOR THE GRAPH ',/,
110      8,' AND THE END POINT FOR THE GRAPH. '),
      READ(5,*) FRQINT,FRQEND
      WRITE(6,160) FRQINT,FRQEND
160      FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE(6,309)
      FORMAT(1,'ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS ',/,
309      8,' FOR THE GRAPH IN DB. '),
      READ(5,*) YLOW, YSTEP
      WRITE(6,359) YLOW, YSTEP
359      FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE(6,310)
      FORMAT(1,'ENTER THE YAXIS HIGH POINT IN DB. '),

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THE05290
THE05300
THE05310
THE05320
THE05330
THE05340
THE05350
THE05360
THE05370
THE05380
THE05390
THE05400
THE05410
THE05420
THE05430
THE05440
THE05450
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THE05470
THE05480
THE05490
THE05500
THE05510
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THE05590
THE05600
THE05610
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THE05670
THE05680
THE05690
THE05700
THE05710
THE05720
THE05730
THE05740
THE05750
THE05760

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      READ(5,*) YHIGH
      WRITE(6,360) YHIGH
      FORMAT(5X,F12.8,/)
360  C
      NMODES = 30
      MODE = (C/A)*(FLOAT(NMODES))
      NPMODE = IFIX(MODE)
      IF((MODE-NPMODE).GT.0.5) NPMODE=NPMODE+1
      RETURN
      END
370  C
      C**ENTDAT
      C**TREQ
      SUBROUTINE TREQ(PI,A,LAM,NMODES,D,KA,KD,KE,NPMODE,ERU,ERL)
      COMPLEX *16 KA(30),KD(30),KE(30),J
      REAL *8 ERU,ERL,PI,A,LAM,T1,X1,T2,KXA,TREQ1,D,X2,TREQ2,ERRREQ,X3
      REAL *8 KKKD,KKKA,TI,TREQ3,ITEMP,W,KXD
      REAL XTEMP
      INTEGER NMODES,NPMODE,NTEMP
      J = (0.0,1.0)
      IF(ERU.LT.ERL) GOTO 309
      X1=(PI/(8.0*A))
      T2 = ((2.0*PI)/LAM)**2.0*(ERU-ERL)
      DO 350 I=1,NMODES
      T1 = X1**2.0
      IF (T1.GT.T2) GOTO 361
      KXA = ((T2-T1)**0.5)
      TREQ1 = -X1*(DCOS(X1*(A-D)))*(DCOSH(KXA*D)) -
      KXA*(DSINH(KXA*D))*(DSIN(X1*(A-D)))
      GOTO 362
      KXA = (T1-T2)**0.5
      TREQ1 = KXA*DSIN(KXA*D)*DSIN(X1*(A-D)) -
      (X1*DCOS(KXA*D)*DCOS(X1*(A-D)))
      X2 = X1 + (PI/(8.0*A*ERU))
      T1 = X2**2.0
      IF(T1.GT.T2) GOTO 371
      KXA = ((T2-T1)**0.5)
      TREQ2 = -X2*(DCOS(X2*(A-D)))*(DCOSH(KXA*D)) -
      KXA*(DSINH(KXA*D))*(DSIN(X2*(A-D)))
      GOTO 372
      KXA = (T1-T2)**0.5)
      TREQ2 = KXA*DSIN(KXA*D)*DSIN(X2*(A-D)) - (X2*DCOS(KXA*D)) *
      DCOS(X2*(A-D))
      IF((TREQ1*TREQ2).LE.0.0) GOTO 380
      X1 = X2
351  C
361  C
362  C
371  C
372  C
      THE05770
      THE05780
      THE05790
      THE05800
      THE05810
      THE05820
      THE05830
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      THE05900
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      THE05960
      THE05970
      THE05980
      THE05990
      THE06000
      THE06010
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      THE06080
      THE06090
      THE06100
      THE06110
      THE06120
      THE06130
      THE06140
      THE06150
      THE06160
      THE06170
      THE06180
      THE06190
      THE06200
      THE06210
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      THE06240

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380      GOTO 351
      ERRREQ = (X2 * 0.00001)
      TTEMP = DABS((TREQ1+TREQ2)/2.0)
      IF(TTEMP.LE.ERRREQ) GOTO 381
      X3 = (X1+X2)/2.0
      T1 = X3**2.0
      IF(T1.GT.T2) GOTO 386
      KXA = ((T2-T1)**0.5)
      TREQ3 = -X3*(DCOS(X3*(A-D)))*(DCOSH(KXA*D)) -
      KXA*(DSINH(KXA*D))*(DSIN(X3*(A-D)))
      GOTO 385
8
386      KXA = (T1-T2)**0.5
      TREQ3 = KXA*DSIN(KXA*D)*DSIN(X3*(A-D))-(X3*DCOS(KXA*D)) *
      IF((TREQ1*TREQ3).LE.0.0) GOTO 387
8
387      X1=X3
      TREQ1=TREQ3
      GOTO 380
      X2=X3
      TREQ2=TREQ3
      GOTO 380
381      T1 = (X1+X2)/2.0
      T2 = T1**2
      IF(T1.LT.T2) GOTO 388
      KXA = (T1-T2)**0.5
      KA(I) = KXA
      GOTO 389
      KXA = (T2-T1)**0.5
      KA(I) = J*KXA
      X1 = X1 + (PI/(8.0*A))
      CONTINUE
      GOTO 307
388      X1 = (PI/(8.0*C*A))
      T2 = ((2.0*PI)/LAM)**2.0*(ERL-ERU)
      DO 310 N = 1,NMODES
389      T1 = X1**2.0
350      IF(T1.GT.T2) GOTO 321
      KXD = ((T2-T1)**0.5)
      TREQ1 = X1*(DSIN(X1*D))*(DSINH(KXD*(A-D)))*
      KXD*(DCOSH(KXD*(A-D)))*(DCOS(X1*D)) -
8
      GOTO 322
      KXD = (T1-T2)**0.5
      TREQ1 = X1*DSIN(X1*D)*DSIN(KXD*(A-D)) - KXD*DCOS(X1*D) *
8
322      X2 = X1 + (PI/(8.0*A*ERL))
      T1 = X2**2.0
      IF(T1.GT.T2) GOTO 331

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THE06250
THE06260
THE06270
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THE06290
THE06300
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THE06380
THE06390
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THE06680
THE06690
THE06700
THE06710
THE06720

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      KXD = ((T2-T1)**0.5)
      TREQ2 = X2*(DSIN(X2*D))*DSINH(KXD*(A-D)) -
      KXD*(DCOSH(KXD*(A-D)))*(DCOS(X2*D))
      GOTO 332
331      KXD = ((T1-T2)**0.5)
      TREQ2 = X2*DSIN(X2*D) *DSIN(KXD*(A-D)) - KXD * DCOS(X2*D) *
      DCOS(KXD*(A-D))
332      IF ((TREQ1*TREQ2).LE.0.0) GOTO 330
      X1 = X2
      GOTO 311
330      ERRREQ = (X2 * 0.00001)
      TTEMP = DABS((TREQ1+TREQ2)/2.0)
      IF (TTEMP.LE.ERRREQ) GOTO 341
      X3 = (X1 + X2)/2.0
      T1 = X3 * 2.0
      IF (T1.GT.T2) GOTO 346
      KXD = ((T2-T1)**0.5)
      TREQ3 = X3*(DSIN(X3*D))*DSINH(KXD*(A-D)) -
      KXD*(DCOSH(KXD*(A-D)))*(DCOS(X3*D))
      GOTO 345
346      KXD = (T1-T2)**0.5
      TREQ3 = X3*DSIN(X3*D)*DSIN(KXD*(A-D)) - KXD*DCOS(X3*D) *
      DCOS(KXD*(A-D))
345      IF ((TREQ1*TREQ3).LE.0.0) GOTO 347
      X1 = X3
      TREQ1 = TREQ3
      GOTO 330
347      X2 = X3
      TREQ2 = TREQ3
      GOTO 330
341      T1 = (X1+X2)/2.0
      KA(N) = T1
      T1 = T1**2
      IF (T1.LT.T2) GOTO 348
      KXD = (T1-T2)**0.5
      KD(N) = KXD
      GOTO 349
348      KXD = (T2-T1)**0.5
      KD(N) = J*KXD
349      X1 = X1 + (PI/(8.0*A))
310      CONTINUE
      GOTO 307
C 307 DO 335 I = 1,NPMODE
      KKKD = ((FLOAT(I)*PI)/(A-D))
      KE(I) = KKKD
335      CONTINUE
C

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THE06730
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THE06990
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THE07170
THE07180
THE07190
THE07200

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NTEMP = NPMODE + 1
IF (NTEMP.GT.NMODES) GOTO 3335
DO 334 I = NTEMP,NMODES
  KKKA = (((2.0*FLOAT(I-NTEMP+1))-1.0)*PI/(2*D))
  KE(I) = KKKA
334 CONTINUE
3335 NTEMP = NTEMP
RETURN
END
C**TREQ
C**PROPAG
SUBROUTINE PROPAG(KA,KE,GAMMA1,Y1,GAMMA2,Y2,PI,LAM,ERU,ERL,W
, UO,NMODES,NPMODE)
8
C
  COMPLEX *16 WUJ,TEMP1,GAMMA1(30),GAMMA2(30),Y1(30),Y2(30),J
  COMPLEX *16 KA(30),KE(30)
  REAL *8 ERU,ERL,PI,LAM,W,UO
  INTEGER NMODES,NPMODE,NTEMP
  J = (0.0,1.0)
  WUJ = J*W*UO
  TEMP1 = ERL*(((2.0*PI)/LAM)**2.0)
  DO 451 I = 1,NMODES
    GAMMA1(I) = CDSQRT(KA(I)**2 - TEMP1)
    Y1(I) = GAMMA1(I)/WUJ
  451 CONTINUE
C
  FOR REGION 2, WE MUST COMBINE THE UPPER REGION, WITH THE LOWER REGION
C
  TEMP1 = (ERU*(((2.0*PI)/LAM)**2.0))
  DO 461 I = 1,NPMODE
    GAMMA2(I) = CDSQRT(KE(I)**2 - TEMP1)
    Y2(I) = GAMMA2(I)/WUJ
  461 CONTINUE
C
  THE NEXT PART ADDS THE REST OF REGION TWO VARIABLES INTO GAMMA2
C
  TEMP1 = (ERL*(((2.0*PI)/LAM)**2.0))
  NTEMP = NPMODE + 1
  IF (NTEMP.GT.NMODES) GOTO 4777
  DO 471 I = NTEMP,NMODES
    GAMMA2(I) = CDSQRT(KE(I)**2 - TEMP1)
    Y2(I) = GAMMA2(I)/WUJ
  471 CONTINUE
C
  4777 RETURN
END
C**PROPAG

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THE07210
THE07220
THE07230
THE07240
THE07250
THE07260
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THE07350
THE07360
THE07370
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THE07460
THE07470
THE07480
THE07490
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THE07590
THE07600
THE07610
THE07620
THE07630
THE07640
THE07650
THE07660
THE07670
THE07680

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C**SMATRI
SUBROUTINE SMATRI(SM11,SM12,SM21,SM22,KA,KD,KE,A,D,NMODES,Y1,Y2,
8 NPMODE,GAMMA2,SB1,SB2,GAMMA1)
C
COMPLEX X *16 SM11(5,5),SM12(5,5),SM21(5,5),SM22(5,5),GAMMA2(30)
COMPLEX X *16 H(30,30),CAPLAM(30),CAPDME(30),S11(30,30),S12(30,30)
COMPLEX X *16 YREG1(30,30),YREG2(30,30),S21(30,30),KA(30),HI(30,30)
COMPLEX X *16 S22(30,30),KD(30),KE(30),DEN(30,30),SB1(5),SB2(5)
COMPLEX X *16 AA(30,30),AB(30,30),ALP,DEL,CT1(30),CT2(30),CT3(30)
COMPLEX X *16 YINVL(30,30),YINV2(30,30),Y1(30),Y2(30),GAMMA1(30)
REAL *8 ALPHA,DELTA,A,D,ZI,WA(130),TEMP
REAL TEMPI
INTEGER NMODES,NMAX,I,ER,NPMODE,IM(5)
C
NMAX = 30
DO 550 I = 1,NMODES
CT1(I) = ((D/2.0) + ((CDSIN(KD(I)*(A-D)))**2)) / ((4*KA(I)))
CT2(I) = ((CDSIN(KA(I)*(A-D)))**2) / ((CDSIN(KD(I)*(A-D)))**2)
CT3(I) = ((A-D)/2.0) - ((CDSIN(2.0*KD(I)*(A-D))) / (4*KD(I)))
CAPLAM(I) = 1.000 / (CDSQRT(CT1(I) + CT3(I)) / CT2(I))
CAPDME(I) = 1.000 / (CDSQRT(CT1(I) + CT3(I)) + CT2(I))
CONTINUE
ALPHA = ((2.0/C/D)**0.5)
ALP = ALPHA
DELTA = ((2.0/(A-D))**0.5)
DEL = DELTA
DO 551 N = 1,NMODES
H(M,N) = 1,NPMODE
DO 552 M = 1,NPMODE
H(M,N) = CAPDME(N) * DEL * ((KE(M)) / ((-1.0)**M) **2 - KE(M)**2)
CONTINUE
NTEMP = NPMODE + 1
IF (NTEMP.GT.NMODES) GOTO 551
DO 555 MM = 1,NPMODES
H(MM,N) = CAPLAM(N) * ALP * (((-1.0)**MM) * (CDCOS(KA(N)*(A-D)))**2) / ((KE(MM)) / (KA(N)**2 - KE(MM)**2))
CONTINUE
CONTINUE
DO 553 I = 1,NMODES
DO 554 J = 1,NMODES
IF (I.NE.J) GOTO 563
YREG1(I,J) = Y1(I)
YREG2(I,J) = Y2(I)
GOTO 554
YREG1(I,J) = (0.0,0.0)
563

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554 YREG2(I,J) = (0.0,0.0)
555 CONTINUE
DO 571 I = 1,NMODES
DO 572 J = 1,NMODES
HT(I,J) = H(J,I)
CONTINUE
572 CONTINUE
571 CALL CMMUL (YREG1,HT,NMODES,AA)
CALL CMMUL (H,AA,NMODES,AB)
CALL CMSUM (YREG2,AB,NMODES,AA)
CALL CMSUB (YREG2,AB,NMODES,S22)
CALL LECTIC(AA,NMODES,NMAX,S22,NMODES,NMAX,0,WA,IER)
DO 580 I = 1,NMODES
DO 581 J = 1,NMODES
IF (I.NE.J) GOTO 582
DEN(I,J) = (1.0,0.0)
GOTO 581
582 DEN(I,J) = (0.0,0.0)
581 CONTINUE
580 CONTINUE
C
C DETERMINE MATRIX FOR PARAMETER S12
C
CALL CMSUM (DEN,S22,NMODES,AA)
CALL CMMUL (HT,AA,NMODES,S12)
C
C DETERMINE MATRIX FOR PARAMETER S21
C
DO 5701 I = 1,NMODES
DO 5702 J = 1,NMODES
S21(I,J) = S12(J,I)*Y1(J)/Y2(I)
5702 CONTINUE
5701 CONTINUE
C
C DETERMINE MATRIX FOR PARAMETER S22
C
CALL CMMUL (HT,S21,NMODES,AA)
CALL CMSUB (AA,DEN,NMODES,S11)
C
C THIS COMPLETES THE S-MATRIX. NOTE, EACH OF THE FOUR PARAMETERS
C ARE MATRICES IN THEMSELVES
C
CALL PACMAN(GAMMA2,NPMODE,NMODES,IM)
DO 540 I = 1,5
DO 541 J = 1,5
SM1(I,J) = S11(I,J)
SM12(I,J) = S12(I,IM(J))

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THE08170
THE08180
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THE08590
THE08600
THE08610
THE08620
THE08630
THE08640

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      SM21(I,J) = S21(IM(I),J)
      SM22(I,J) = S22(IM(I),IM(J))
541      CONTINUE
      SB1(I) = GAMMA1(I)
      SB2(I) = GAMMA2(IM(I))
540      CONTINUE
C
      RETURN
      END
C**SMATRI
C**CASCAD
      SUBROUTINE CASCAD(SM11,SM12,SM21,SM22,GAMMA1,GAMMA2,COSTWI,DIBECs,
      NMODES,NSTRIP,ST11,ST12,ST21,ST22)
C
      COMPLEX *16 ST11(5,5),ST12(5,5),ST21(5,5),ST22(5,5)
      COMPLEX *16 SS11(5,5),SS12(5,5),SS21(5,5),SS22(5,5)
      COMPLEX *16 SM11(5,5),SM12(5,5),SM21(5,5),SM22(5,5)
      COMPLEX *16 SD11(5,5),SD12(5,5),SD21(5,5),SD22(5,5)
      COMPLEX *16 SE11(5,5),SE21(5,5),SE22(5,5)
      REAL *8 COSTWI(20),DIBECs(19),AC,AR,AI,ATT
      REAL OUTPUT,AB
      INTEGER NMODES
C
      DO 851 I=1,5
      DO 852 J=1,5
      ST11(I,J) = SM11(I,J)
      SD11(I,J) = SM11(I,J)
      ST12(I,J) = SM12(I,J)
      SD12(I,J) = SM12(I,J)
      ST21(I,J) = SM21(I,J)
      SD21(I,J) = SM21(I,J)
      ST22(I,J) = SM22(I,J)
      SD22(I,J) = SM22(I,J)
      CONTINUE
851      CONTINUE
      TEMP1=SM11(1,1)
      AC = CDABS(TEMP1)
      NP = 5
      DO 861 II = 1,NSTRIP
      CALL CASCAD(ST11,ST12,ST21,ST22,SD12,SD22,SD11,NP,GAMMA2,
      COSTWI,II),NP)
      IF(II.EQ.NSTRIP) GO TO 861
      DO 853 I=1,5
      DO 854 J=1,5
      SD11(I,J) = SM11(I,J)
      SD12(I,J) = SM12(I,J)
      SD21(I,J) = SM21(I,J)

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THE08650
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THE08700
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THE08990
THE09000
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THE09100
THE09110
THE09120

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      SD22(I,J) = SM22(I,J)
854   CONTINUE
855   CALL CASCAD(ST11,ST21,ST12,ST22,SD11,SD21,SD12,SD22,NP,GAMMA1,
      8 DO 855 I=1,5
        DO 856 J=1,5
          SD11(I,J) = SM11(I,J)
          SD12(I,J) = SM12(I,J)
          SD21(I,J) = SM21(I,J)
          SD22(I,J) = SM22(I,J)
        CONTINUE
      856 CONTINUE
855 CONTINUE
861 RETURN
      END
C**CASCAD
C**TRANS
SUBROUTINE TRANSM(STE12,STE21,STE22,G,Z,N,X12,Y21,Z22)
C
      COMPLEX *16 STE12(5,5),STE21(5,5),STE22(5,5),X12(5,5)
      COMPLEX *16 Y21(5,5),Z22(5,5),G(5),ZC,ZV(5)
      REAL *8 Z
      INTEGER N
C
      ZC = Z
      DO 955 I = 1,N
        ZV(I) = CDEXP(-G(I)*ZC)
      955 CONTINUE
      DO 950 J = 1,N
        DO 951 I = 1,N
          X12(I,J) = ZV(I)*STE12(I,J)
          Y21(I,J) = STE21(I,J)*ZV(J)
          Z22(I,J) = ZV(I)*STE22(I,J)*ZV(J)
        CONTINUE
      951 CONTINUE
      950 CONTINUE
      END
C**TRANS
C**DSUM
SUBROUTINE DSUM(SA11,SA12,SA21,SA22,SC11,SC12,SC21,SC22,MM,SE11,
      8 SE12,SE21,SE22)
C
      COMPLEX *16 SA11(5,5),SA12(5,5),SA21(5,5),SA22(5,5)
      COMPLEX *16 SC11(5,5),SC12(5,5),SC21(5,5),SC22(5,5)
      COMPLEX *16 SE11(5,5),SE12(5,5),SE21(5,5),SE22(5,5)
      COMPLEX *16 AA(5,5),AB(5,5),AC(5,5),DEN(5,5)
      REAL *8 ZT,WA(30)

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THE09130
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THE09510
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THE09590
THE09600

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C      INTEGER MM, NMAX, IER
      DO 1050 I = 1, MM
      DO 1051 J = 1, MM
      IF(I, NE, J) GOTO 1060
      DEN(I, J) = (1.0, 0.0)
      GOTO 1051
      DEN(I, J) = (0.0, 0.0)
      CONTINUE
      CONTINUE
      NMAX = 5
      FIRST TO DEVELOP THE SE12 MATRIX
      CALL CMMUL(SC11, SA22, MM, AA)
      CALL CMSUB(DEN, AA, MM, AB)
      CALL CMMUL(SC11, SA21, MM, AA)
      CALL LECTIC(AB, MM, NMAX, AA, MM, NMAX, 0, WA, IER)
      CALL CMMUL(SA12, AA, MM, AC)
      CALL CMSUM(SA11, AC, MM, SE11)
      NOW TO DEVELOP SE12
      ZT = 1.0
      CALL CMRNMU(SC12, ZT, MM, AA)
      CALL LEQITC(AB, MM, NMAX, AA, MM, NMAX, 2, WA, IER)
      CALL CMMUL(SA12, AA, MM, SE12)
      NOW TO DEVELOP SE21
      CALL CMMUL(SA22, SC11, MM, AA)
      CALL CMSUB(DEN, AA, MM, AB)
      CALL CMRNMU(SA12, ZT, MM, AA)
      CALL LECTIC(AB, MM, NMAX, AA, MM, NMAX, 0, WA, IER)
      CALL CMMUL(SC21, AA, MM, SE21)
      NOW TO DEVELOP SE22
      CALL CMMUL(SA22, SC12, MM, AA)
      CALL LEQITC(AB, MM, NMAX, AA, MM, NMAX, 2, WA, IER)
      CALL CMMUL(SC21, AA, MM, AB)
      CALL CMSUM(AB, SA22, MM, SE22)
      RETURN
      END
C**D SUM

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THE09610
THE09620
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THE09640
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THE10000
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THE10040
THE10050

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# APPENDIX G

## SAMPLE CAD OUTPUT TO CRT

ENTER 1 IF YOU WANT THE COMPUTER TO DESIGN AND TEST  
A FILTER FOR YOU OR "0" IF YOU WANT TO ENTER YOUR OWN DESIGN.  
THIS IS A PROGRAM USED TO DESIGN FILTERS.  
YOU WILL BE PROMPTED FOR THE REQUIRED INPUTS.  
ENTER THE FILTER NUMBER FOR YOUR GRAPH.  
7

INPUT HALF OF THE WAVE GUIDE WIDTH  
AND DISTANCE FROM THE CENTER OF THE GUIDE TO SEPTUM EDGE.  
1.14300000 0.00200000

INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN  
FIRST THE CENTER OF THE GUIDE AND SEPTUM EDGE:  
AND SECOND BETWEEN SEPTUM WALL AND WAVEGUIDE WALL  
1.00000000 1.00000000

NOW YOU WILL INPUT THE FILTER PARAMETERS  
ENTER THE BEGINNING AND END FREQUENCY FOR THE PASSBAND  
OF THE FILTER.  
8.40000000 8.80000000

NOW ENTER THE FREQUENCY AND DB DOWN FOR THE  
TAIL OF THE FILTER  
9.00000000 25.00000000

NOW ENTER THE RIPPLE IN DB ON THE TOP OF THE PASSBAND.  
0.15000000

THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH.  
ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ  
7.80000000

ENTER THE FREQUENCY INTERVAL IN MHZ AND  
THE NUMBER OF STEPS THAT YOU WOULD LIKE  
20.00000000 101

ENTER THE INTERVAL MARKS FOR THE GRAPH  
AND THE END POINT FOR THE GRAPH.  
0.20000000 9.80000000

ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS  
FOR THE GRAPH IN DB.  
-30.00000000 10.00000000

ENTER THE YAXIS HIGH POINT IN DB.  
0.0

CENTER FREQUENCY IS 8.5875



SO = 0.0 RH = 0.187D+00 N = 6

HERE IS THE S11(I) ELEMENTS  
0.73588D+00-0.95755D+00 0.97438D+00-0.97620D+00 0.97438D+00-0.95755D+00  
0.73588D+00

HERE ARE THE 7 CONDUCTING STRIP WIDTHS  
AND THE 6 RESONATOR WIDTHS

0.09060973 2.04797381  
0.47936749 2.12270522  
0.59607291 2.12795985  
0.61337277 2.12795985  
0.59607291 2.12270522  
0.47936749 2.04797381  
0.09060573

LISTED BELOW IS THE POWER TRANSMITTED THRU YOUR  
FILTER FOR EACH RESPECTIVE FREQUENCY POINT.

DB LOSS, FREQ IN GHZ, ENERGY CHECK	-98.016602	7.8000	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-96.233795	7.8200	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-94.411285	7.8400	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-92.546646	7.8600	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-90.637238	7.8800	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-88.680145	7.9000	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-86.672180	7.9200	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-84.609802	7.9400	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-82.489044	7.9600	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-80.305496	7.9800	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-78.054214	8.0000	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-75.729599	8.0200	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-73.325287	8.0400	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-70.833969	8.0600	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-68.247253	8.0800	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-65.555344	8.1000	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-62.746765	8.1200	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-59.807846	8.1400	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-56.722168	8.1600	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-53.469696	8.1800	1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK	-50.025482	8.2000	1.0000





DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-46	357971	8.2200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-42	426056	8.2400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-38	174652	8.2600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-33	527115	8.2800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-28	371704	8.3000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-22	537704	8.3200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-15	764248	8.3400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-7	856019	8.3600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-1	104898	8.3800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	011268	8.4000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	050644	8.4200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	000850	8.4400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	076754	8.4600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	135845	8.4800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	086494	8.5000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	011467	8.5200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	012955	8.5400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	085820	8.5600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	145542	8.5800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	131783	8.6000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	061411	8.6200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	004745	8.6400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	015078	8.6600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	073450	8.6800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	109286	8.7000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	077027	8.7200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	013639	8.7400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	010848	8.7600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	080297	8.7800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	070596	8.8000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-0	028788	8.8200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-1	449127	8.8400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-5	840528	8.8600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-1	100730	8.8800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-15	888702	8.9000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-20	082428	8.9200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-23	781113	8.9400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-27	083817	8.9600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-30	065778	8.9800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-32	782669	9.0000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-35	276154	9.0200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-37	578247	9.0400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-39	714006	9.0600	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-41	703720	9.0800	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-43	563568	9.1000	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-45	307175	9.1200	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-46	945923	9.1400	1.0000
DB	LOSS	FREQ	IN	GHZ	ENERGY	CHECK	-48	489426	9.1600	1.0000



DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-49	9425969	9.325678	1.800	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-51	9425678	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-52	9425748	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-53	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-55	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-56	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-57	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-58	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-59	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-60	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-61	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-62	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-63	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-64	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-65	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-66	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-67	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-68	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-69	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-70	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-71	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-71	9425672	9.325678	1.2000	1.0000
DB	LOSS	S	FREQ	IN	GHZ	E	GY	CHECK	-71	9425672	9.325678	1.2000	1.0000





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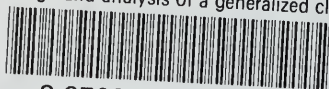
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